



Summer 8-2005

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**Analysis of Trenton-Stones River Oil Production in the Swan Creek Oil and Gas
Field via Well Log Correlation Using Landmark**

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8-03-05

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Abstract

This research project examined oil production in the Swan Creek Oil and Gas Field, which lies within the Appalachian fold-thrust belt in Hancock and Claiborne Counties, Tennessee. A significant amount of Trenton-Stones River oil has been recovered from the field, but the nature of the oil reservoir remains unclear. It is widely accepted in Tennessee that oil is produced where sub-vertical fractures enhance the porosity and permeability of otherwise tight rocks, but other possibilities exist. Alternatively, the locally enhanced permeability may be related to previously unrecognized stratigraphic features, or small-scale thrust faults may provide pathways for the migration of oil into the wells. These three alternative hypotheses will be considered in the light of digital logs recently obtained for 26 Swan Creek wells along with 17 paper logs. Allegheny Wireline Services provided the digital well logs to The University of Tennessee with permission from Tengasco and Miller Petroleum. The logs were analyzed using Landmark OpenWorks and StratWorks software, which was obtained by the University under a grant from Landmark Graphics Corporation.

Introduction

The Swan Creek Oil and Gas Field has been the site of hydrocarbon exploration for more than 40 years. A number of petroleum companies, large and small, have spent time there. The larger petroleum companies, Amoco and ARCO, did not deem it commercially viable to develop the field, in part because their investments in exploration would be more profitable in other areas including offshore in the Gulf of Mexico, where there were much larger oil reservoirs. However, smaller companies, such as Tengasco and Miller Petroleum, have continued to operate and drill successful wells in the Swan Creek field and elsewhere in East Tennessee.

Tengasco has oil and gas properties both in the Appalachian over-thrust region of eastern Tennessee and in Kansas. They make substantial use of seismic reflection technology to identify drilling targets. However, in eastern Tennessee the mountainous topography and thick vegetation make it more difficult and expensive to use seismic equipment than in Kansas. Numerous wells have been drilled in Tennessee without the benefit of seismic data, and the logs from these wells then become the main source of geologic information about the field.

Historically, wells were logged and paper logs were archived for additional study. Maps were drawn by hand, but organizing and interpreting large numbers of paper well logs is awkward and cumbersome. When logs are available in digital format, computer software programs such as Landmark provide valuable tools to efficiently display and correlate a large number of well logs, and to quickly produce machine-contoured maps.

Tengasco and other operators have more than 45 oil and gas wells in the Swan Creek field. Gas production comes primarily from the Knox Dolostone while oil production is mostly from the Trenton-Stones River Groups (Hatcher et. al., 2001). This project focuses primarily on the oil producing Trenton-Stones River Groups, but structure contour maps for the top of the Knox Dolostone were also produced.

Regional Geology

The Swan Creek Field lies in Hancock and Claiborne Counties. The area the well logs cover and this project focuses on, includes approximately 4820 acres, mostly in Hancock County. The field lies within the Appalachian foreland fold-thrust belt, which

is defined by numerous thrust faults and related folding that has created many complex structures capable of trapping oil. The major faults in the region are the Wallen Valley, Hunter Valley, Clinchport, and Copper Creek thrust faults, which Milici et al. (1979) included in the Imbricate Thrust structural province. With few exceptions, these faults originate in a basal décollement near the top of crystalline basement, cut upward through the overlying strata including the carbonate rocks of the Knox Group and ultimately emerge at the surface. In some instances, they change trajectory and flatten into bedding of the overlying Middle Ordovician limestones (Milici et. al., 1979). When deeply eroded, the thrust sheets formed by these faults produce the Valley and Ridge topography in East Tennessee.

The Trenton-Stones River Group, which produces oil in the Swan Creek field, lies within the footwall of the Clinchport thrust fault (Figure 1). This situation is unusual, because typically hanging wall anticlines above thrust faults are explored more often for hydrocarbons than footwall anticlines (Hatcher et. al., 2001). None of the faults, however, brought basement rock to the surface, and were instead confined to the sedimentary rocks above during the movement of the sheets to the northwest (Harrison and Milici, 1977). Because of the unusual position of the anticline and the complexity of the surrounding geology, convenient oil reservoir models have been hard to formulate for the field.

Data Processing and Correlation

The vast majority of the project revolved around processing the available well log data. Most of the processing involved digital well log correlations using Landmark StratWorks, but the paper well logs were also used where digital logs were not available.

The first step in processing the data was loading it onto the Department of Earth and Planetary Sciences' Landmark server. The data consisted of 26 well logs in log ASCII standard (LAS) format that Allegheny Wireline Services donated to the University for student instruction, with permission from Tengasco, Inc, and Miller Petroleum.

The digital well logs were examined in OpenWorks to insure that they had been loaded correctly. In Landmark, the names of the wells were shortened to abbreviations and can be seen in Table 1. To examine the data files a well log template was created to display selected well log curves in the Correlation window (Figure 2). The template, named Chad1, contains six tracks for the curves to be displayed. The curves chosen, from left to right as seen in the template, were Gamma Ray, Density, Resistivity Deep, Resistivity Medium, Photoelectric (PE), and Caliper. This template allows for the data in the LAS files to be viewed; however, not all of the wells were logged with the same tools, so the set of curves available is not uniform for all wells. For example, some wells have only the Gamma Ray and Density curves, while others have all six curves.

Seven marker boundaries were chosen in the Trenton-Stones River interval. These were the tops of the Hermitage Formation, the Carters Limestone, the Lebanon Limestone, the Ridely Limestone, the Pierce Limestone, the Murfreesboro Limestone, and the Wells Creek Formation. An eighth marker boundary was placed at the bottom of the Wells Creek Formation and top of the Knox Group. A type log supplied by Jonathan Evenick (personal communication) was used as the basis for placement of the marker boundaries (Figure 3). A base map of the Swan Creek field was created to show relative positions of the wells and to aide in the correlation process (Figure 4). Multiple Lines of Section (Landmark terminology) were created within the Landmark project from this

map. A Line of Section is a segmented line, not necessarily straight, that connects multiple wells that are relatively close together and ideally close to a straight line so that correlation of those wells is made easier. The marker boundaries were plotted on all the wells in a particular Line of Section. Once the wells in a particular Line of Section were correlated, another Line of Section was started. This Line of Section intersected a previously completed Line of Section so that boundary markers would be consistent between different Lines of Section.

Once the Lines of Section were completed all 26 wells were lined up from southwest to northeast. Working down from the Hermitage Limestone, each boundary was datummed, i.e., the vertical positions of all wells containing such boundary were repositioned so that the boundary pick would be made flat. This made rechecking the boundary picks much easier and allowed thickening and thinning features to be compared and contrasted. This also made areas of duplication due to thrust faulting much easier to identify.

The 17 paper logs were correlated from southwest to northeast. The depths of boundary markers were recorded and later entered into empty data files in the Landmark system. The paper logs were used solely to improve the maps by including more boundary markers. Trying to find faults due to areas of duplication was not attempted.

Contouring

Once all the well logs had been correlated, contour and isochore maps were created based on the eight boundary markers. This was done using the Mapview window in StratWorks. Maps containing contour anomalies, such as bulls-eying, were addressed

and boundary markers readjusted if deemed necessary. The mapping algorithm that Mapview uses to create contour and isochore maps produced some anomalies that would most likely have been smoothed out if hand drawn but are not too significant in the maps provided. Also, faults were not illustrated on the contour maps, but a separate map was created to help visualize their locations (Figure 5).

Some wells are too distant from the structure to possess many of the boundary markers and provide little information to the project. The THALL1 is so distant that none of the boundary markers are present and, therefore, figures provided in the Appendices exclude it to allow better illustration of the field.

Cross Sections

After the contour and isochore maps were created, cross-sections were made along the lines seen in Figure 6, using the Cross Section window in StratWorks. The Cross Section window automatically smoothes and interprets the lines, however, it is often incorrect. Because of this the lines were straightened based on the points actually seen in the wells and not those calculated between.

The cross-sections provide a good visualization of boundary relationships across the area and the amount of thickening that occurred in a particular formation. The presence of faults is marked in Appendix C with a black dash on the well logs. The amount that was duplicated due to faulting, though, could not be illustrated, but can be inferred via thickening of units that possess faults.

Results and Discussion

Analysis of the well log data illustrates that the structure present in the Swan Creek Oil field is a narrowly cresting anticline that trends northeast-southwest. The structure is clearly visible on each of the structure contour maps in Appendix A. Three structurally high locations in the formations are present around the WREED2, PREED5, and SLAWN3 wells. These structural highs widen to include more wells as depth is increased. The structural highs also create a saddle-like depression between WREED2 and PREED5 on the structure contour maps.

While these structural highs are consistent with depth, the thicknesses of the beds are not. The thickening is largely confined to the Carters Limestone. Through correlation of the well logs, 19 faults were identified (Figure 5). The faults mainly occur in the northeastern part of the field and along the crest of the anticline. Most of these faults exist in the Carters Limestone, and were seen in wells SLAWN5, DCRSS1, SLAWN3, JJHN1, HS3, FPORT1, and FPORT2. Three of the faults, however, were located just above the Hermitage Formation in wells PRCE1 and CSMT1. The Carters Limestone faults are located more along the crest of the anticline and southeastern limb in the northeast, while the Hermitage Formation faults are on the northwestern limb in the northeast.

These structural highs exist for two reasons. The first can be seen in the structure contour map of the Knox Dolostone (Figure A.8). The Knox Dolostone is already structurally high at these locations, causing the younger formations deposited above it to be high as well. The second is the faulting that occurred in the Carters Limestone. The extent of the faulting can most easily be seen in the Carters-Lebanon isochore map (Figure B.2). The greatest amounts of structural thickening are located in and around the

SLAWN3 and to the south and southwest of the PREED5. Small-scale thrust faulting in the Carters Limestone caused it to thicken, especially in areas that were already structurally high. Due to these being small-scale faults only the largest faults that caused significant sections of duplication can be identified in the well logs. It is very likely that faulting occurred throughout the area but is too small to identify in the well logs.

Hydrocarbon Production and Structure

The hydrocarbon production at the Swan Creek Oil Field appears to be a coincidence between two factors. The best oil wells are near the highest point on the anticline, close to the axis, at locations where the Carters Limestone is thickened by small-displacement thrust faults. Some of the best gas producing wells in the field are the WREED2, LLAWN 2, and SLAWN4 (Zurawski, 2004). All of those wells lie on the limbs of the anticline and are near structural highs at the depth of the Knox Group. Since nearly all of the gas production is from the Knox Group, the faulting observed in the Carters Limestone has not affected the gas production from the Swan Creek field significantly.

Oil production, in contrast, is predominantly from the Carters Limestone. The best oil producing wells are the PREED5 and PREED8 (Zurawski, 2004). These wells lie on the crest of the anticline close to a structural high. Significant thickening due to faulting was observed in these wells as can be seen in Figure B.2. Faulting of the Carters Limestone almost certainly increased the porosity and permeability of the oil reservoir, allowing better flow of oil into the well bores.

Conclusions

1. The greatest oil production appears to be associated with thickening due to small-scale thrust faulting in the Carters Limestone in areas that are already structurally high because of the underlying anticline.
2. Conceptually, small-scale thrust faults increased the porosity and permeability of the reservoir, and allowed better migration of oil into the wells.
3. It is not possible to determine what area is being drained by each well due to the complexity of the structure and the limited amount of information that could be gained from the well logs about the fault morphology in the Carters Limestone.
4. Additional locations exist within the Swan Creek field and other areas of East Tennessee where oil wells similar to the PREED5 and PREED8 can be attempted.

Acknowledgements

There are several groups of people to whom I am grateful for making my time at the University of Tennessee so rewarding. I have benefited both academically and socially from being associated with the faculty and students of the Department of Earth and Planetary Sciences. I am particularly grateful to my thesis advisor, Dr. Richard T. Williams. His guidance and support were instrumental in the completion of this project.

There are a number of others whose assistance should be recognized. I would like to thank Jonathon Evenick for helping me with various computer programs and providing me with a crash-course on geophysical well log characteristics of the Trenton-Stones River Group. I am also grateful to Jeff Bailey and Tengasco, Inc; to Dr. Gary Bible and

Miller Petroleum; and to Harold Kimball and Allegheny Wireline Services for their generous donation of Swan Creek field well logs to The University of Tennessee.

The University of Tennessee acknowledges support of this project by Landmark Graphics Corporation via the Landmark University Grant Program.

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- Harris, Leonard D., and Milici, Robert C., 1977, Characteristics of Thin-Skinned Style of Deformation in the Southern Appalachians, and Potential Hydrocarbon Traps: Geological Survey Professional Paper, v. 1018, p. 1-28.
- Hatcher Jr., Robert D., Williams, Richard T., and McCown, Micheal W., 2001, Swan Creek Field: Isolated Success or Tip of the Iceberg?: The Oil and Gas Journal, v. 99, Iss. 40.
- Milici, Robert C., Harris, Leonard D., and Statler, Anthony T., 1979, An Interpretation of Seismic Cross Sections in the Valley and Ridge of Eastern Tennessee: Tennessee Division of Geology: Oil and Gas Seismic Investigations, Series I.
- Zurawski, Ronald, P., 2004, Oil and Gas Activity in Tennessee During 2003: Presented at the 33rd Annual Meeting of the Tennessee Oil and Gas Association in Knoxville, Tennessee.

Figures and Tables

Well Name	Abbreviation
Bobby Yeary #2	BYRY2
Cheryl Smith #1	CSMT1
Colson #2	CLSON2
Deanna Cross #1	DCRSS1
Dewey Sutton #1	DSUTN1
Fred Portrum #1	FPORT1
Fred Portrum #2	FPORT2
Gary Patterson #2	GPATT2
Hazel Sutton #2	HS2
Hazel Sutton #3	HS3
Hugh Roberts #1	HROB1
Jeff Johnson #1	JJHN1
Laura J Lawson #1	LLAWN1
Laura J Lawson #2	LLAWN2
Laura J Lawson #3	LLAWN3
Laura J Lawson #4	LLAWN4
Paul Reed #1	PREED1
Paul Reed #3	PREED3
Paul Reed #4	PREED4
Paul Reed #5	PREED5
Paul Reed #6	PREED6
Paul Reed #7	PREED7
Paul Reed #8	PREED8
Paul Reed #9	PREED9
Pierce #1	PRCE1
Stephen Lawson #1	SLAWN1
Stephen Lawson #2	SLAWN2
Stephen Lawson #3	SLAWN3
Stephen Lawson #4	SLAWN4
Stephen Lawson #5	SLAWN5
Stephen Lawson #8	SL8
Ted Hall #1	THALL1
Worlie Purkey #2	PRKY2
Worlie Purkey #3	PRKY3
Warren Reed #2	WREED2

Table 1 - List of well names and abbreviation used in Landmark.

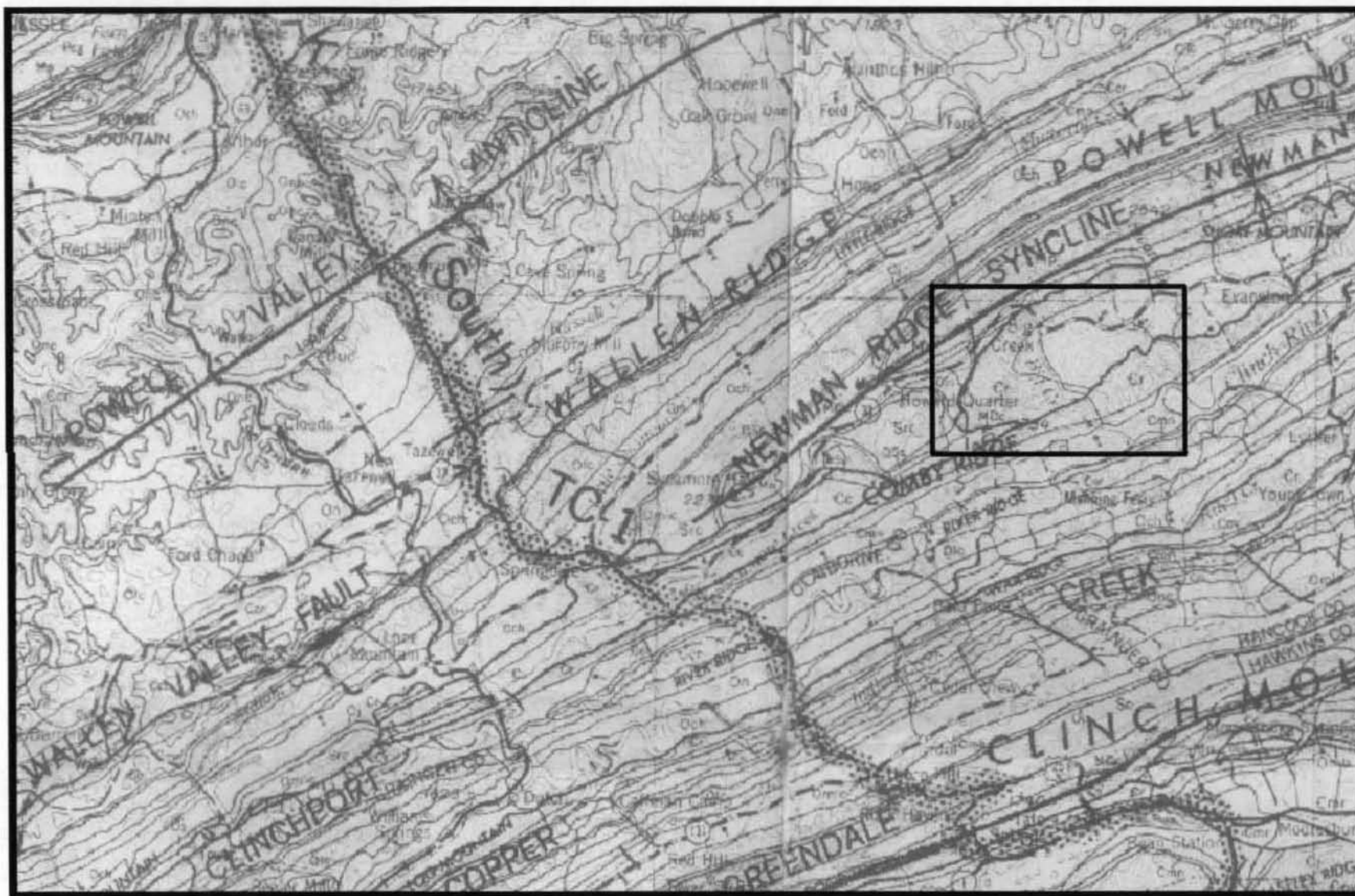


Figure 1 - Geologic map of northeastern Tennessee, showing the Swan Creek Oil and Gas Field (outlined in black) and the surrounding major faults (Wallen Valley and Clinchport). (Hardeman et al, 1966).

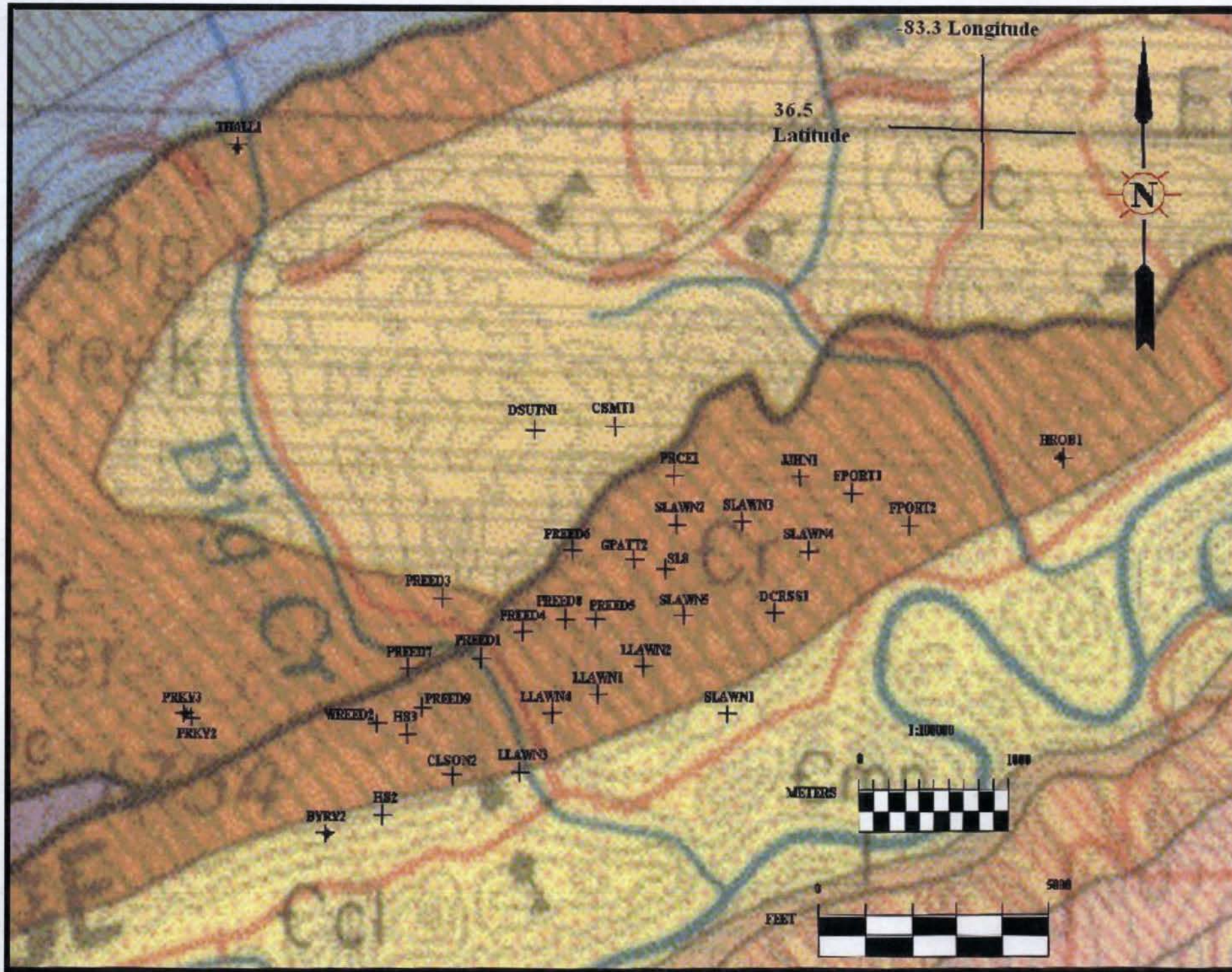


Figure 2 - Geologic map of the Swan Creek Oil and Gas Field with approximate locations of wells.

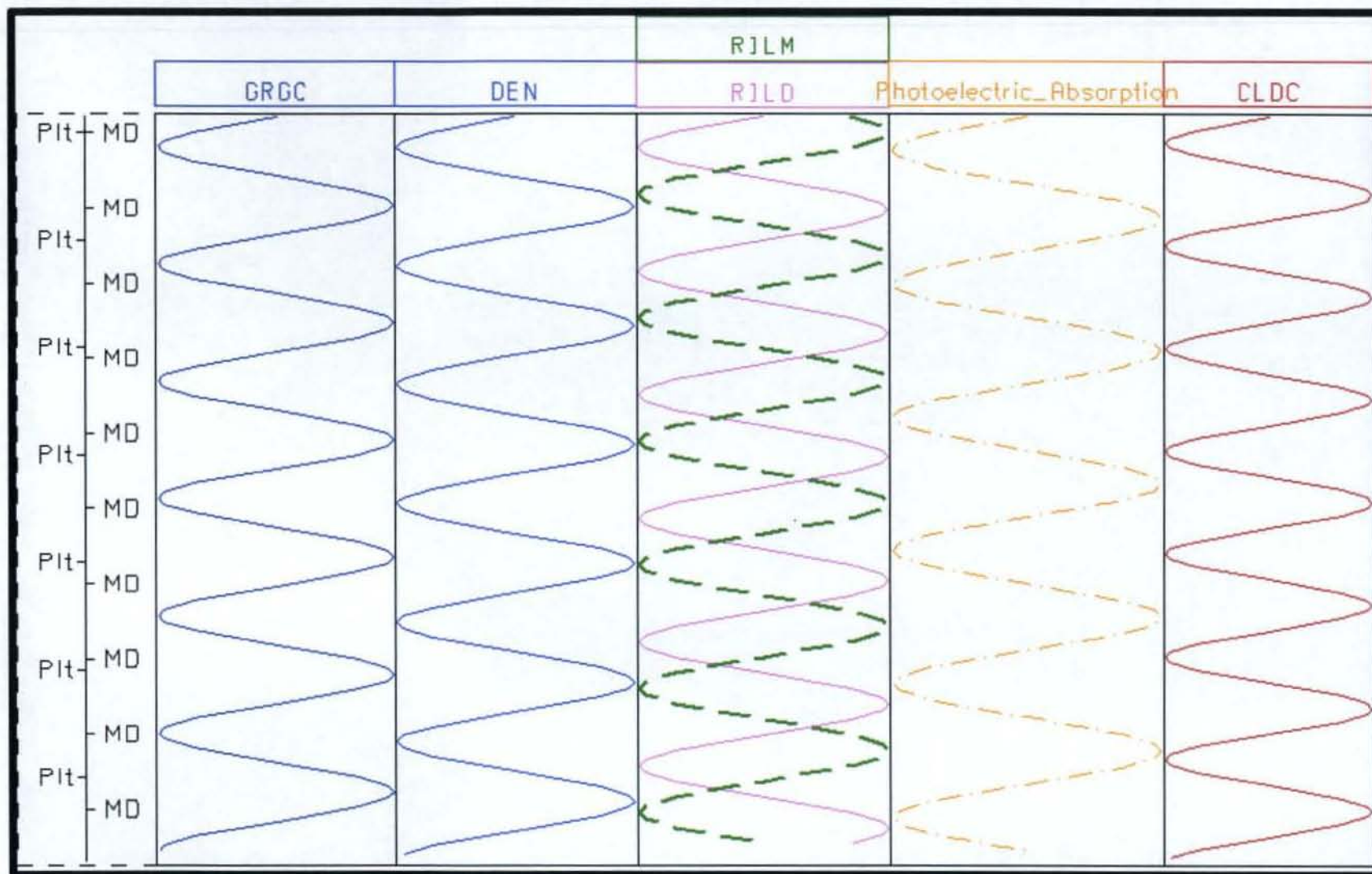


Figure 3 - Well template Chad1 with Gamma Ray, Density, Resistivity Medium and Deep, Photoelectric, and Caliper curves.

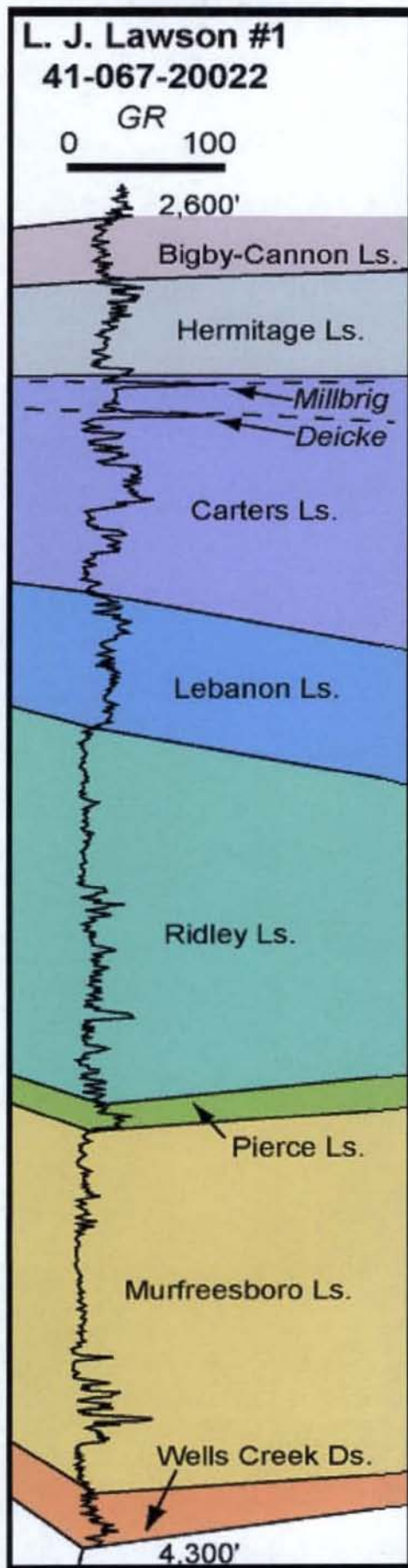


Figure 4 - Type log L. J. Lawson #1 used to identify the boundary markers in wells located in the Swan Creek Field. (Evenick, 2005)

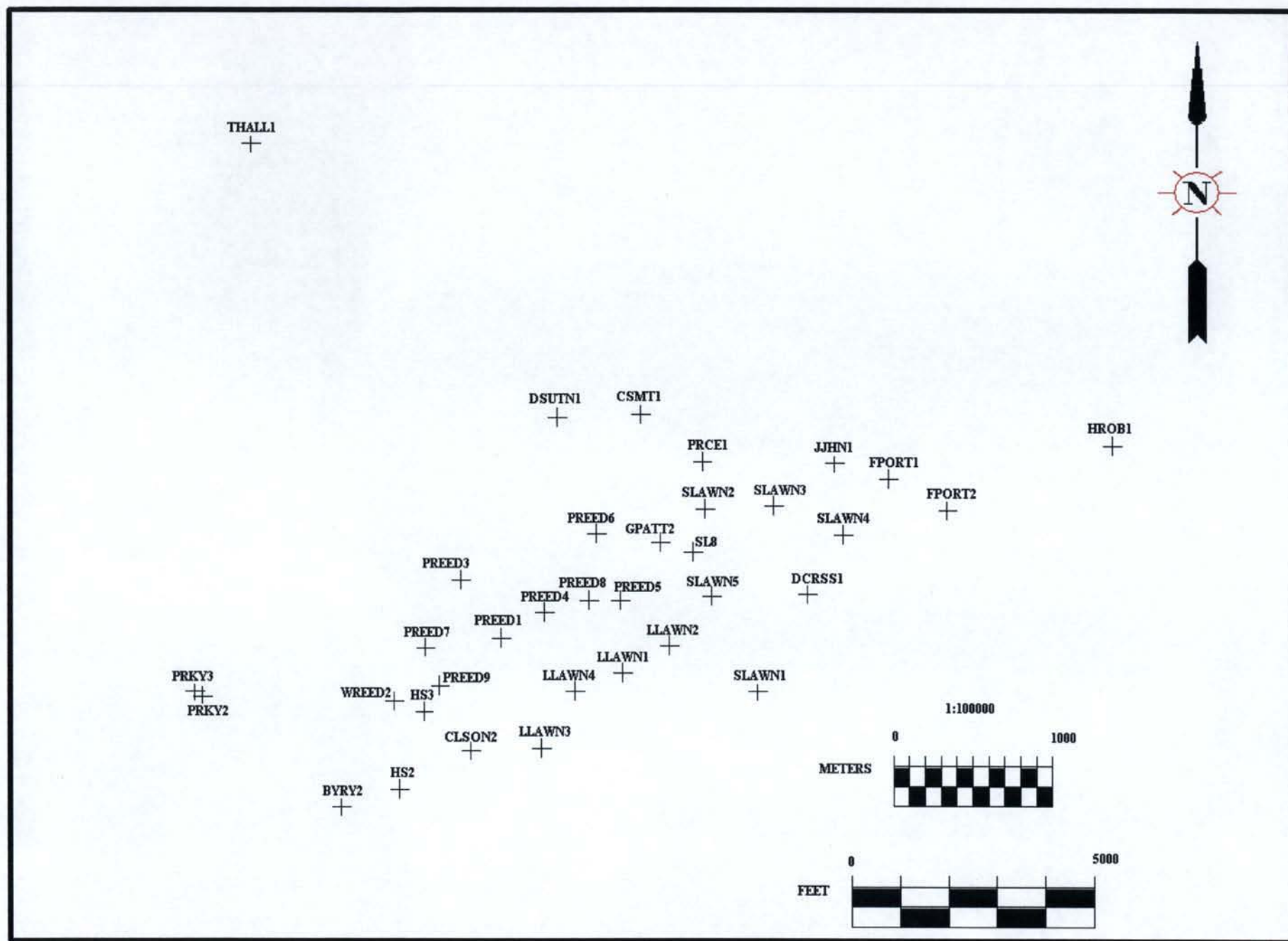


Figure 5 - Base map of the Swan Creek Oil and Gas Field with labeled wells.

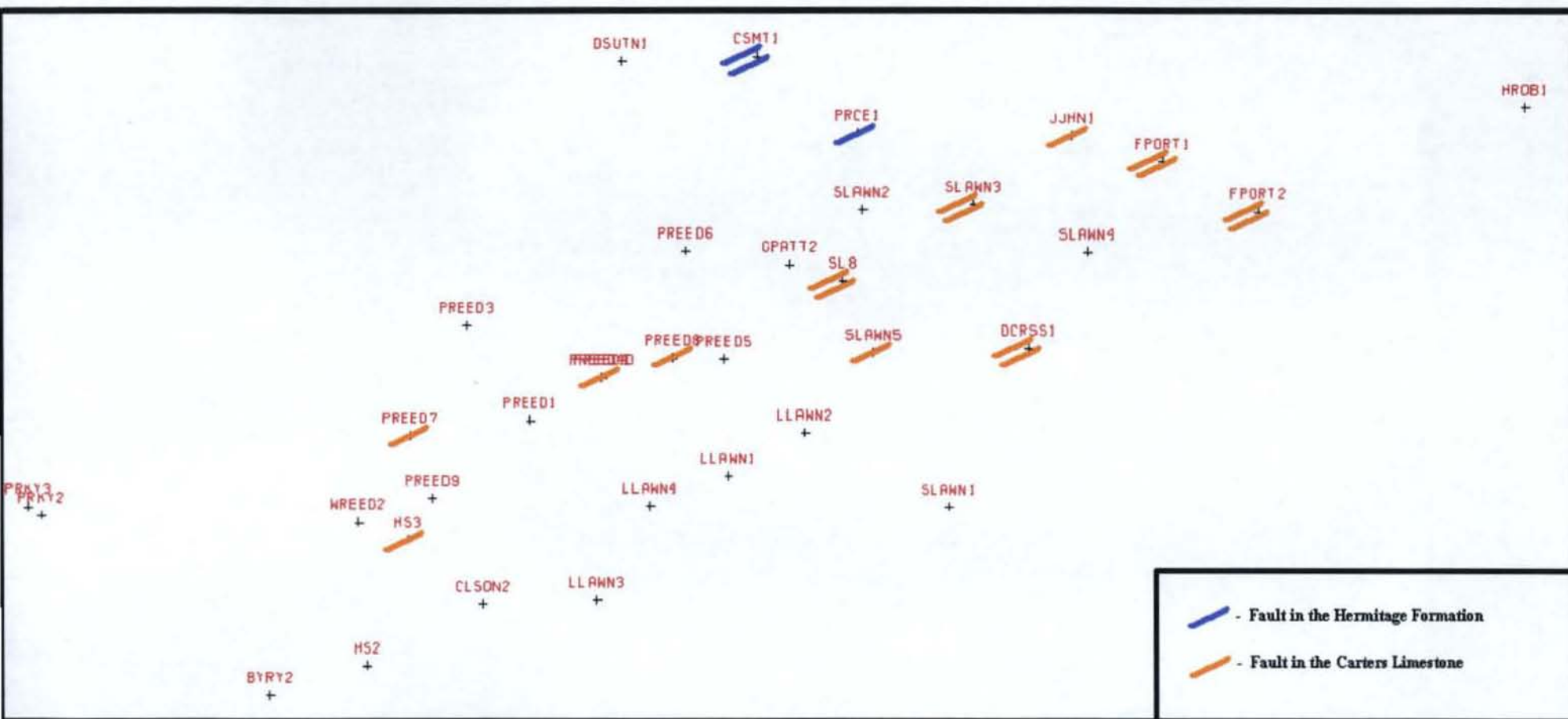


Figure 6 - Base map of the Swan Creek Oil Field illustrated with fault locations. The PREED5 may possess faults, however, it was a paper log and the attempt to identify faults was not made.

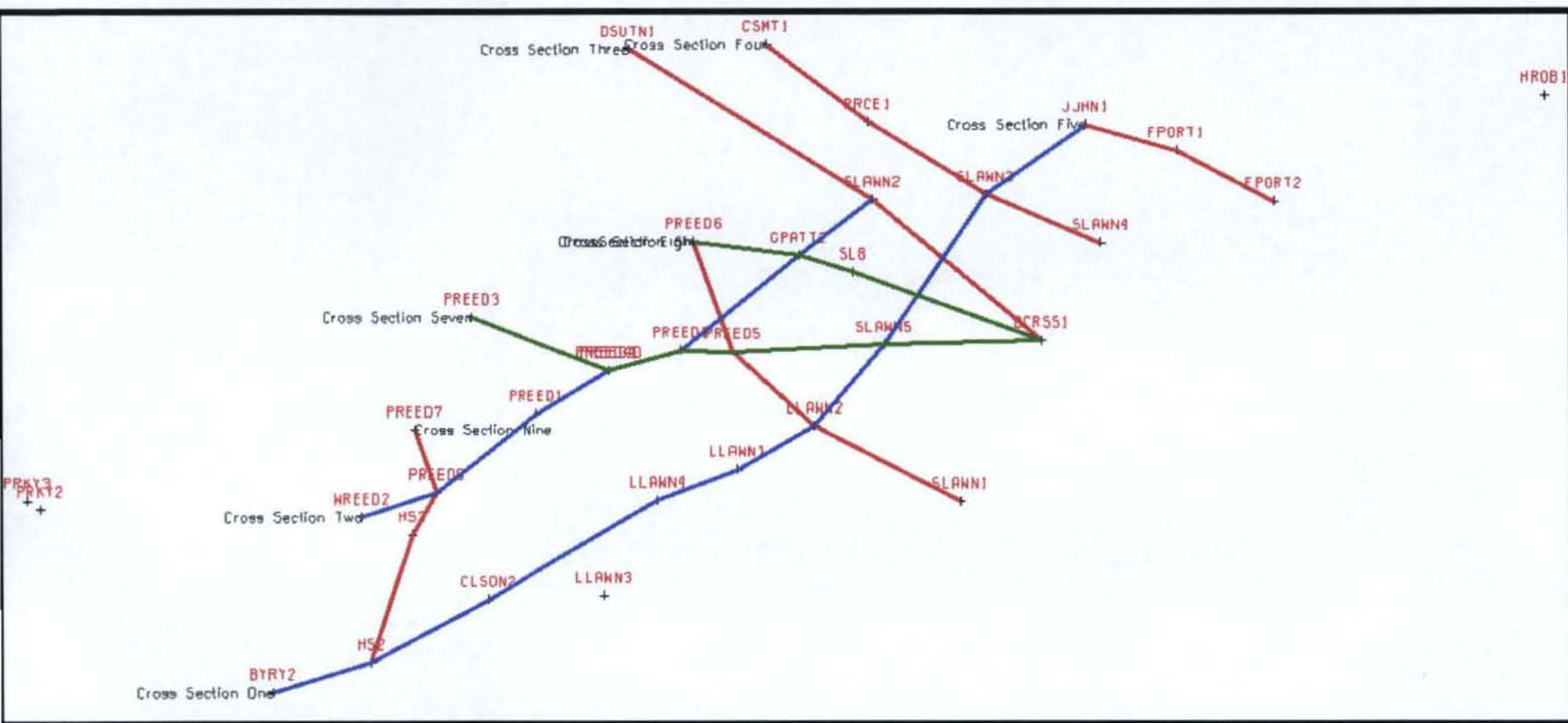
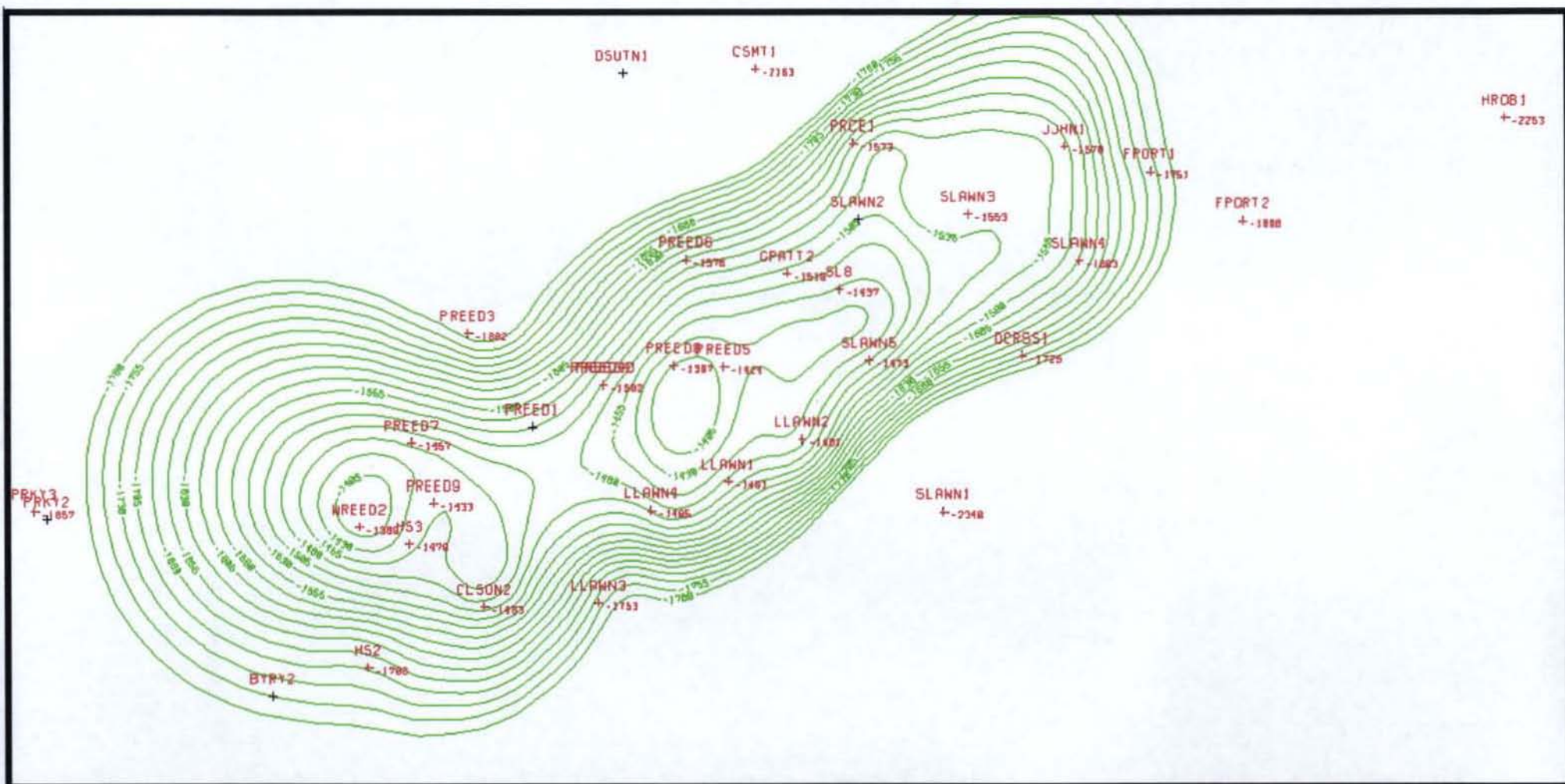
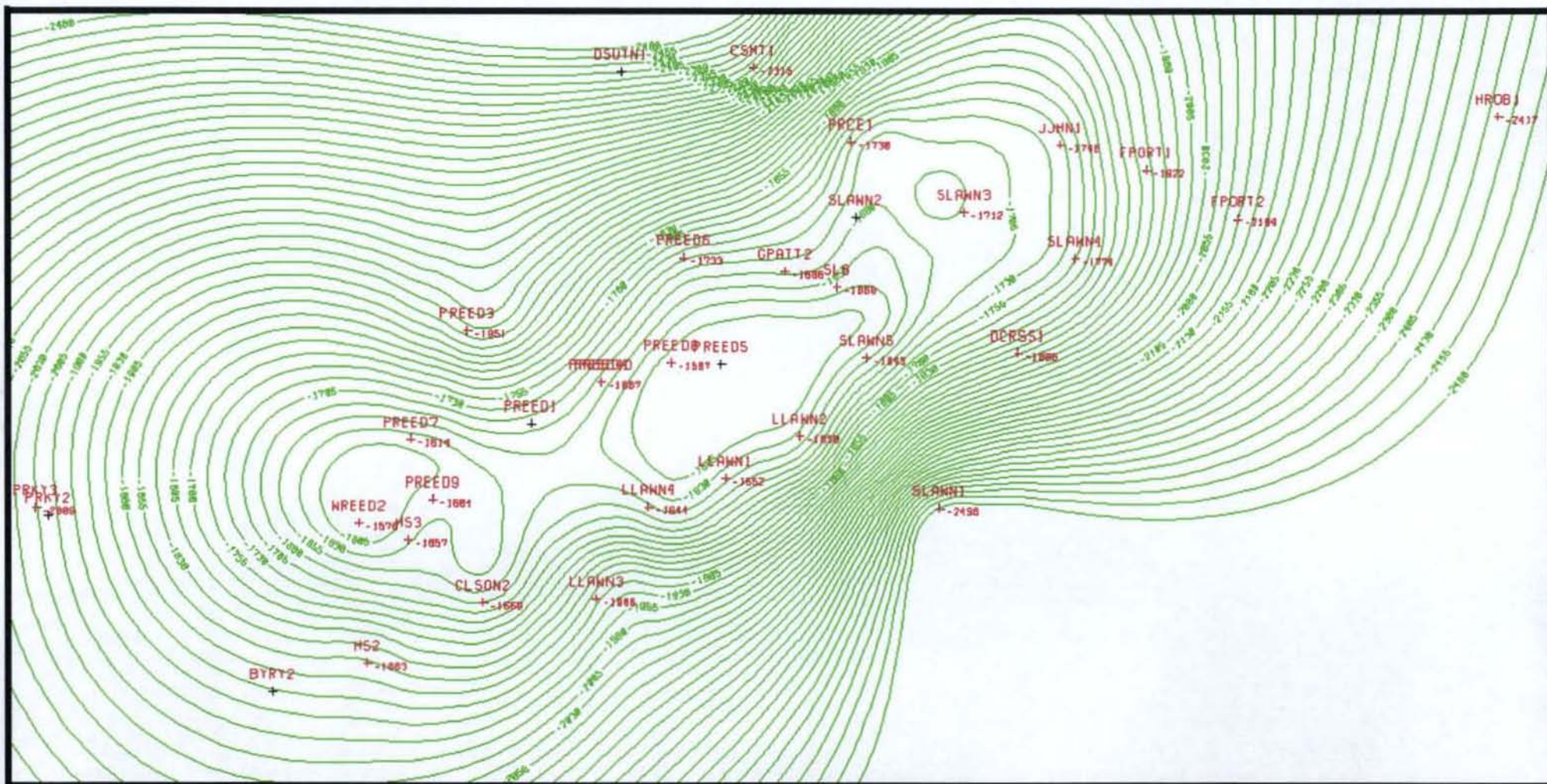


Figure 7 - Map of cross-section lines in the Swan Creek Oil and Gas Field. Lines were made different colors to help distinguish between them and see what wells they contain.

Appendices

Appendix A: Structure Contour Maps of the Swan Creek Oil Field





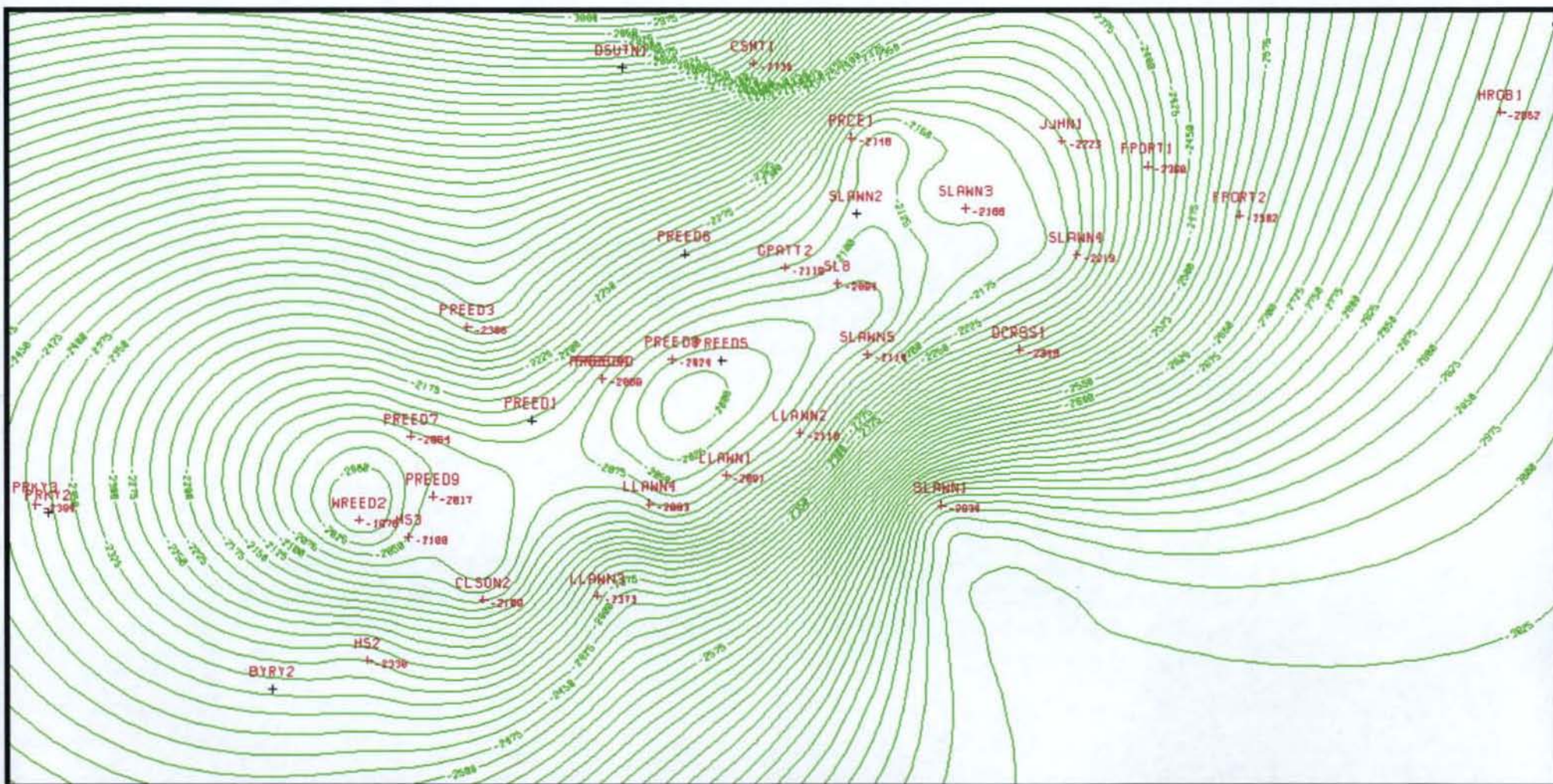


Figure A.5 - Contour map of the Pierce Limestone.

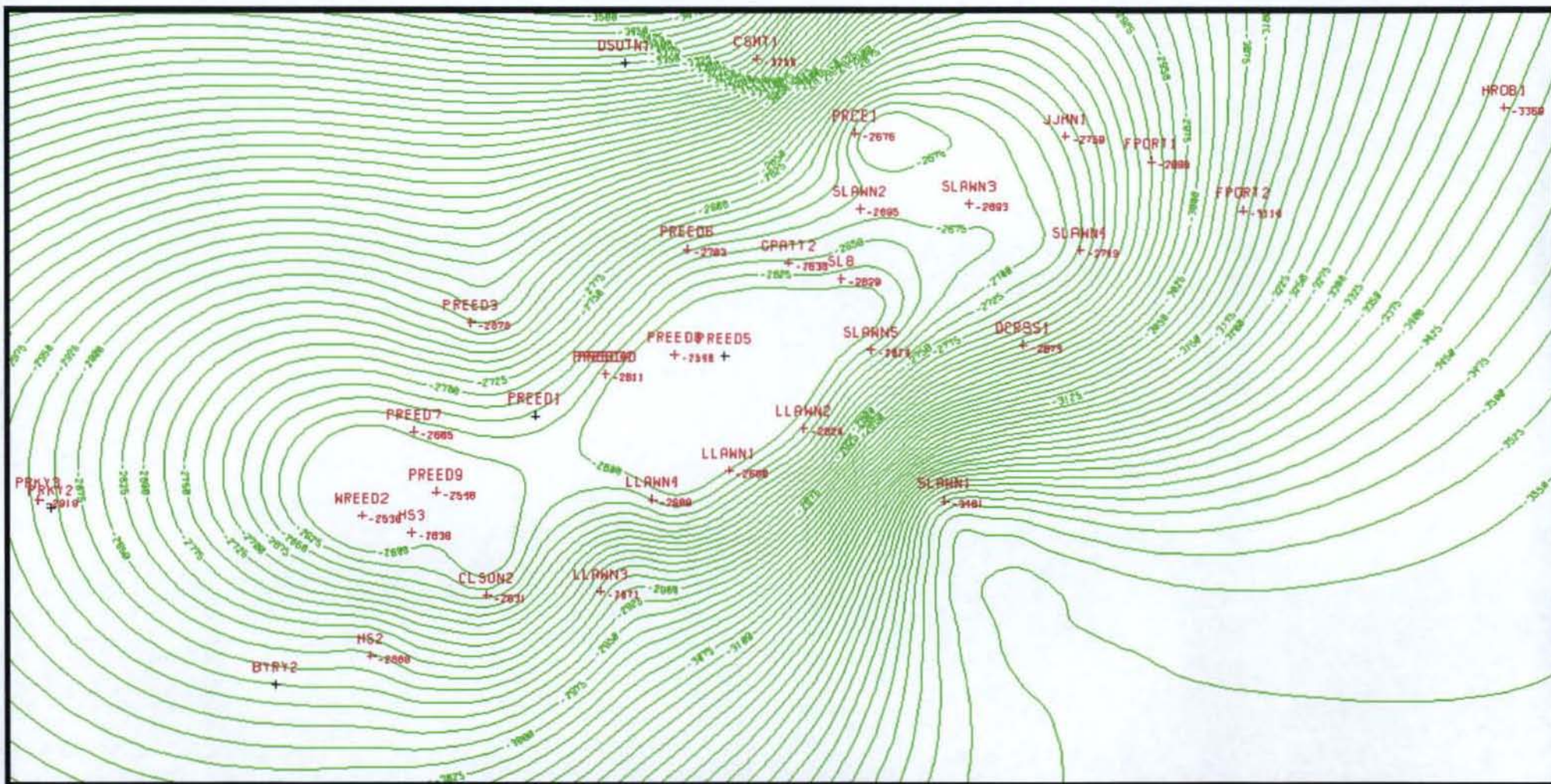


Figure A.7 - Contour map of the Wells Creek Formation.

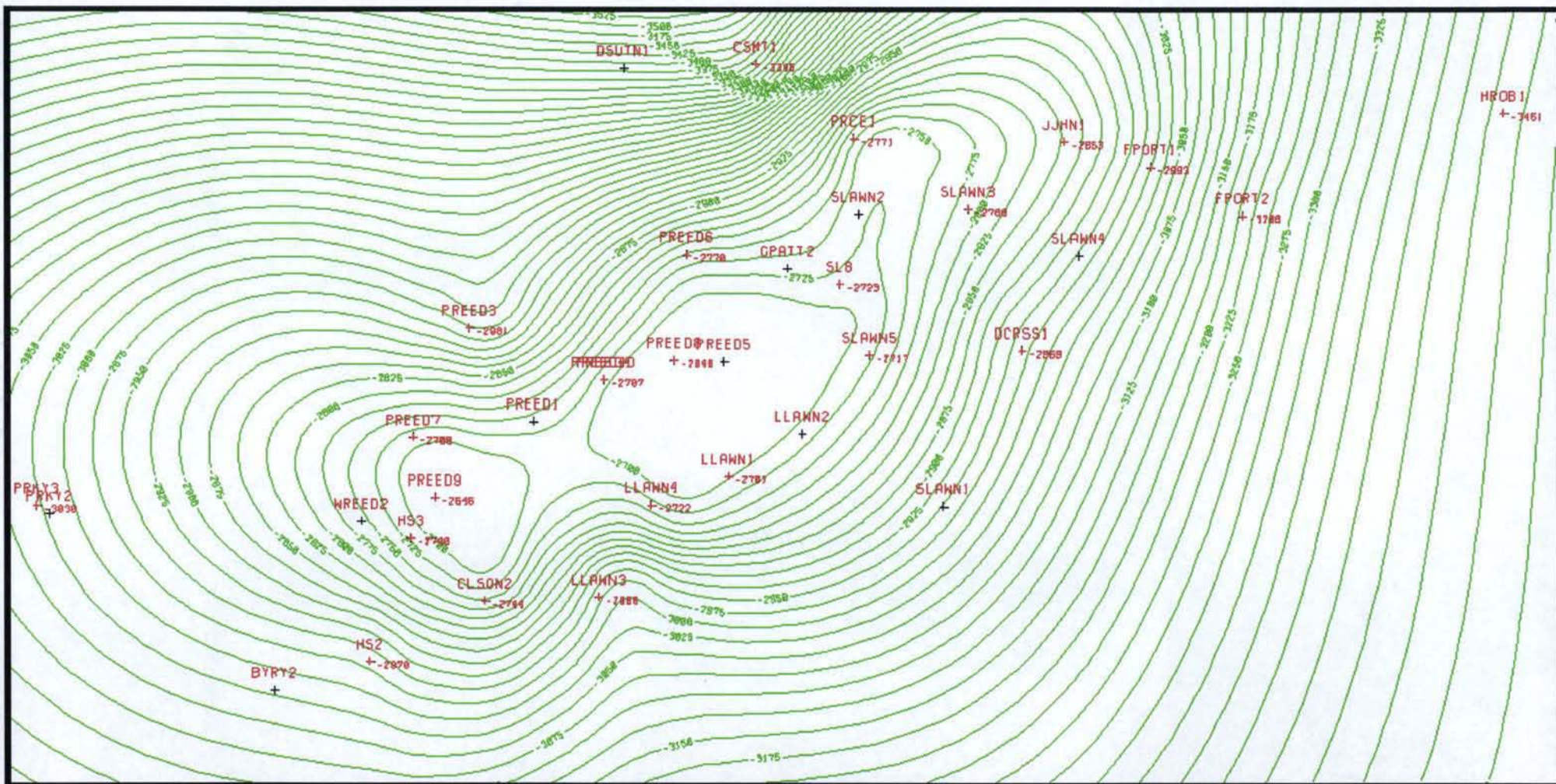


Figure A.8 - Contour map of the Knox Dolostone.

Appendix B: Isochore Maps of the Swan Creek Oil Field

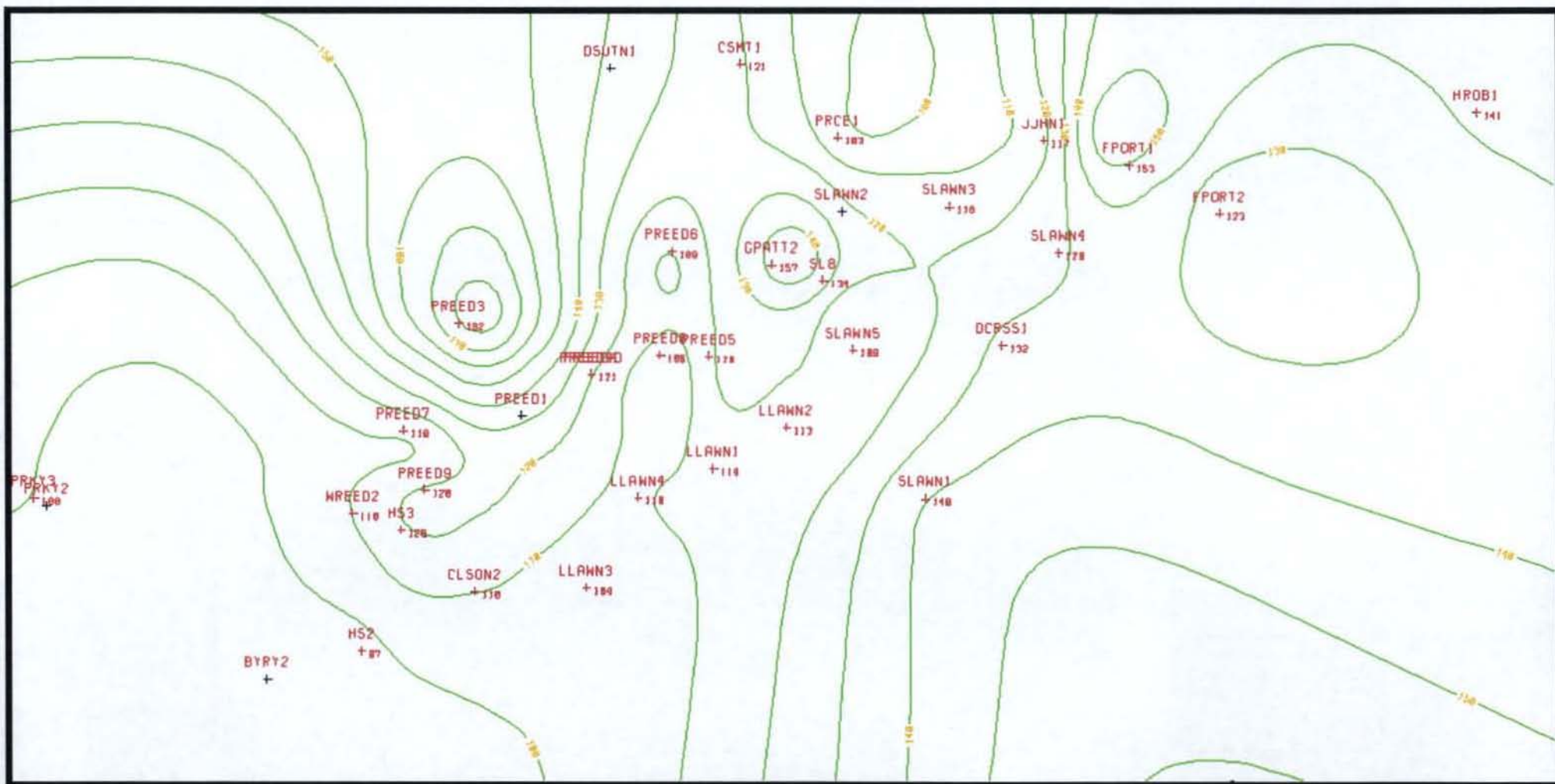


Figure B.1 - Isochore map of the Hermitage Formation.

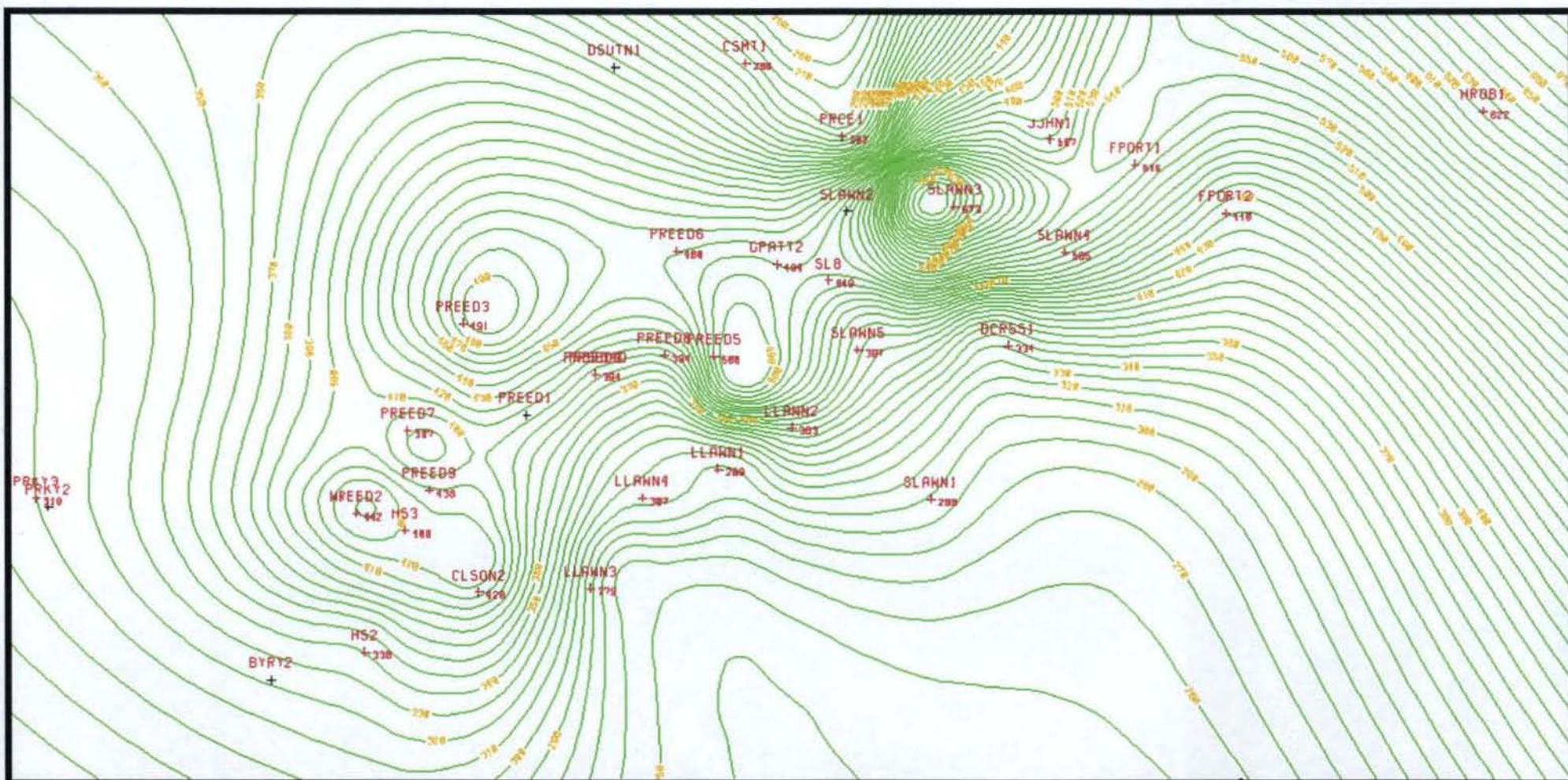


Figure B.2 - Isochore map of the Carters Limestone.

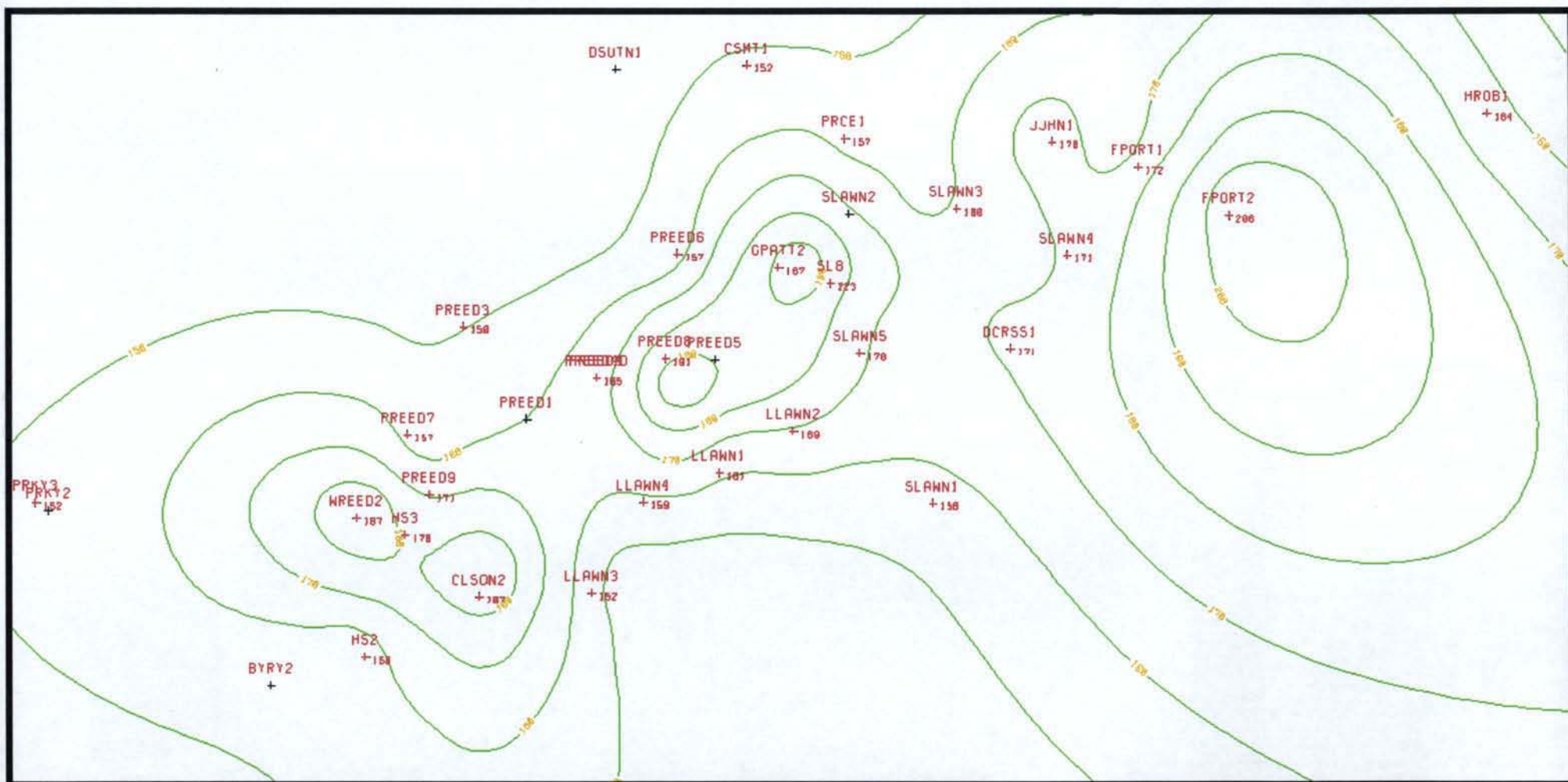


Figure B.3 - Isochore map of the Lebanon Limestone.

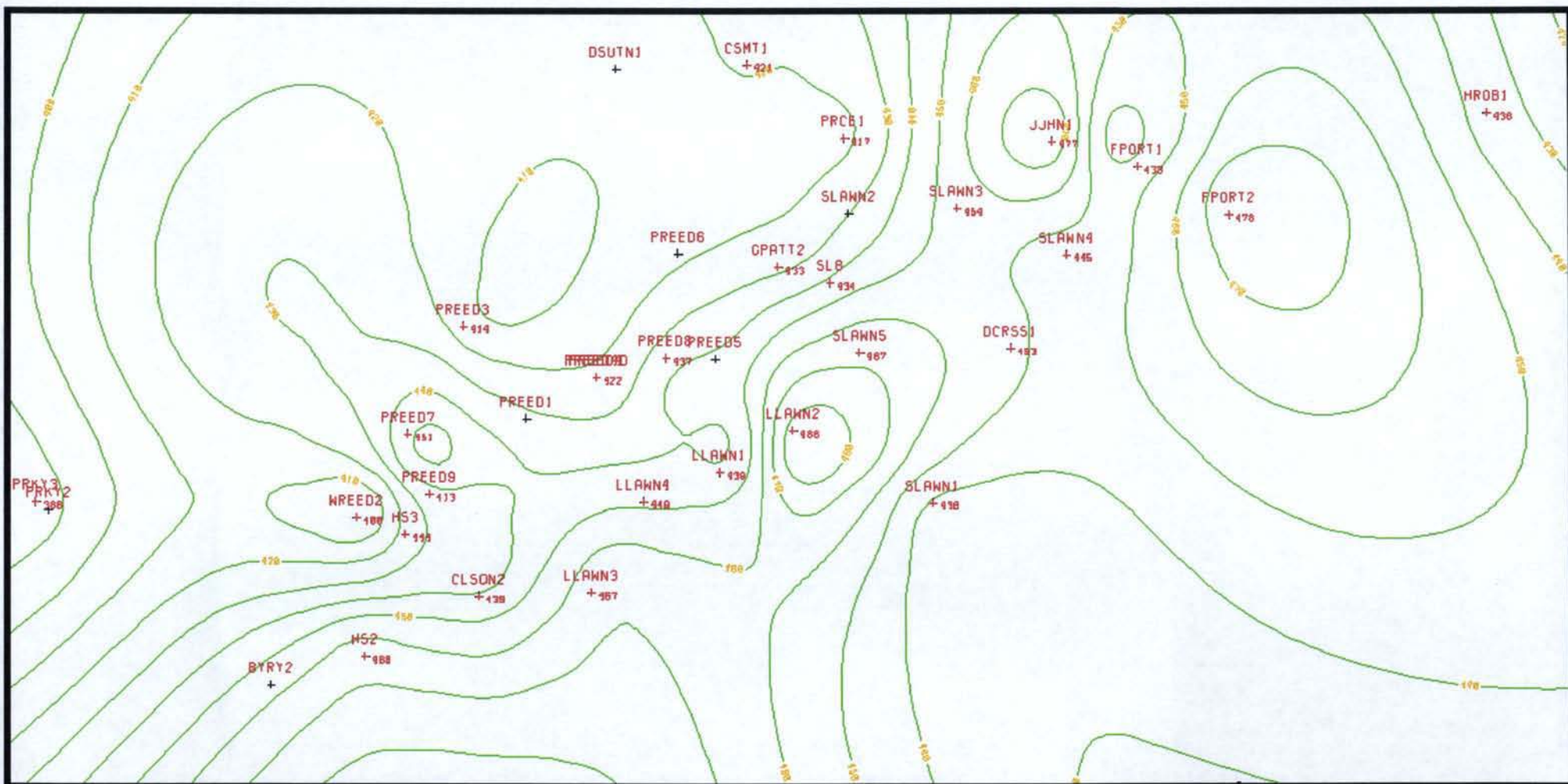


Figure B.4 - Isochore map of the Ridely Limestone.

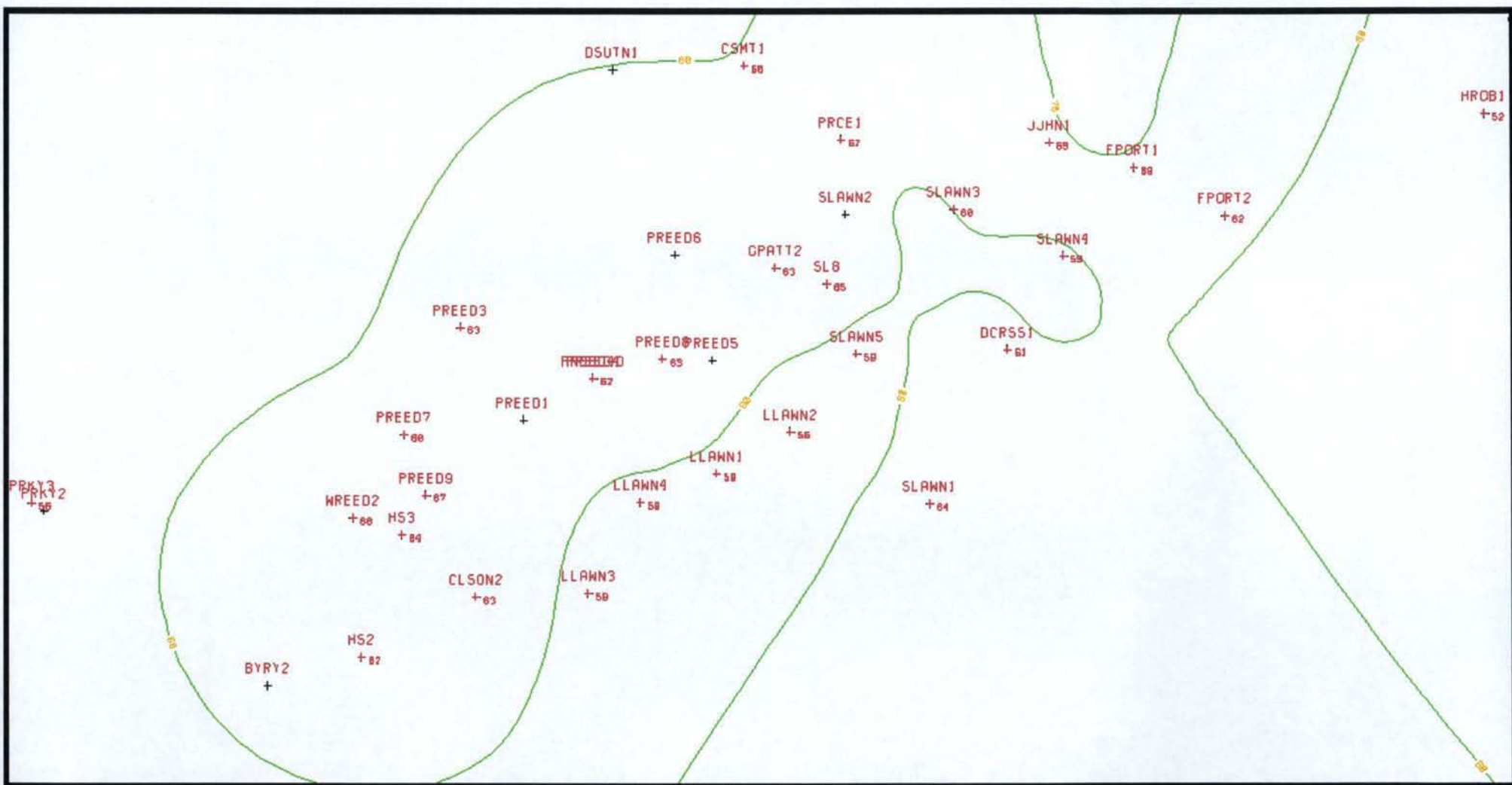


Figure B.5 - Isochore map of the Pierce Limestone.

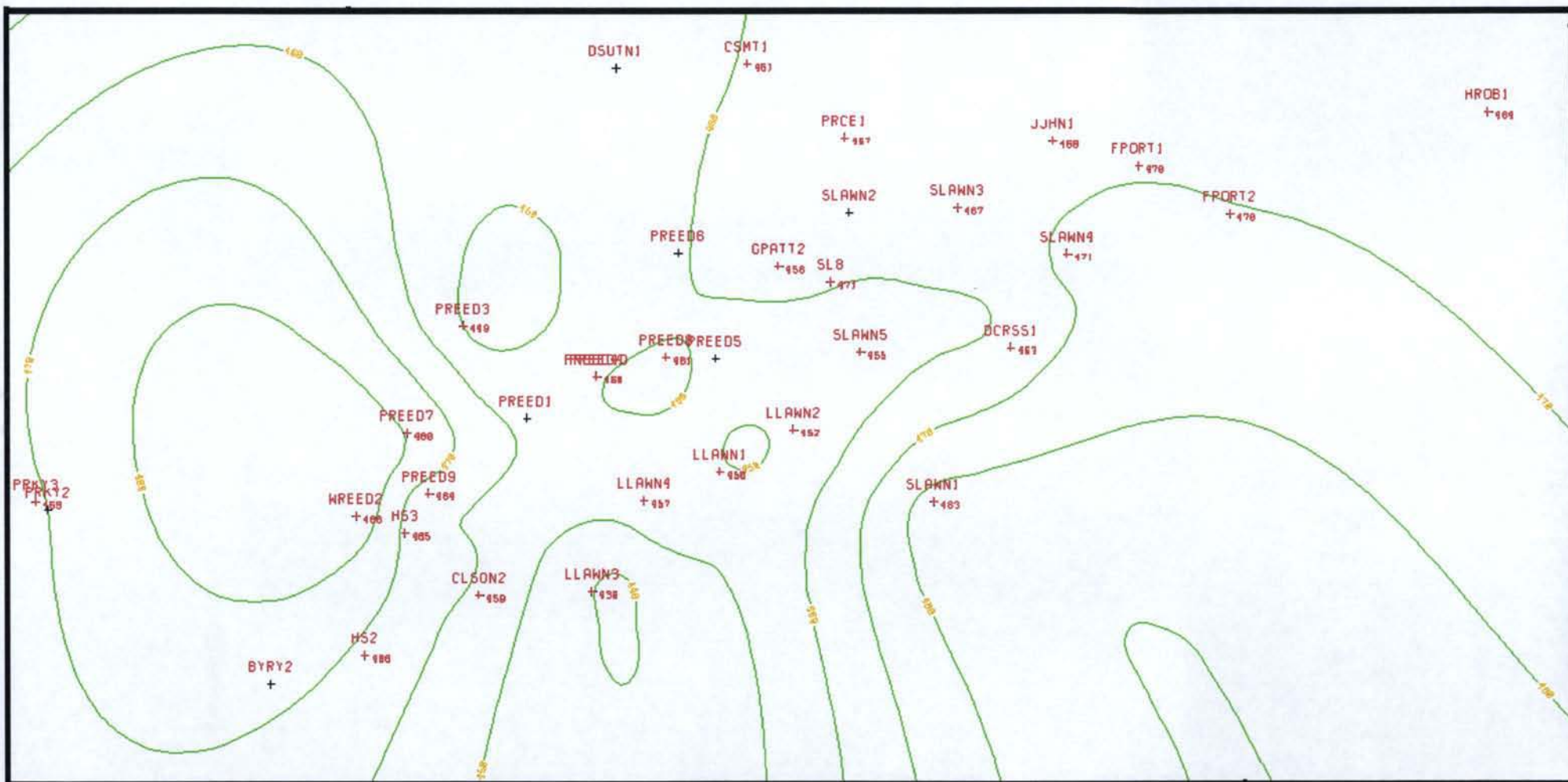


Figure B.6 - Isochore map of the Murfreesboro Limestone.

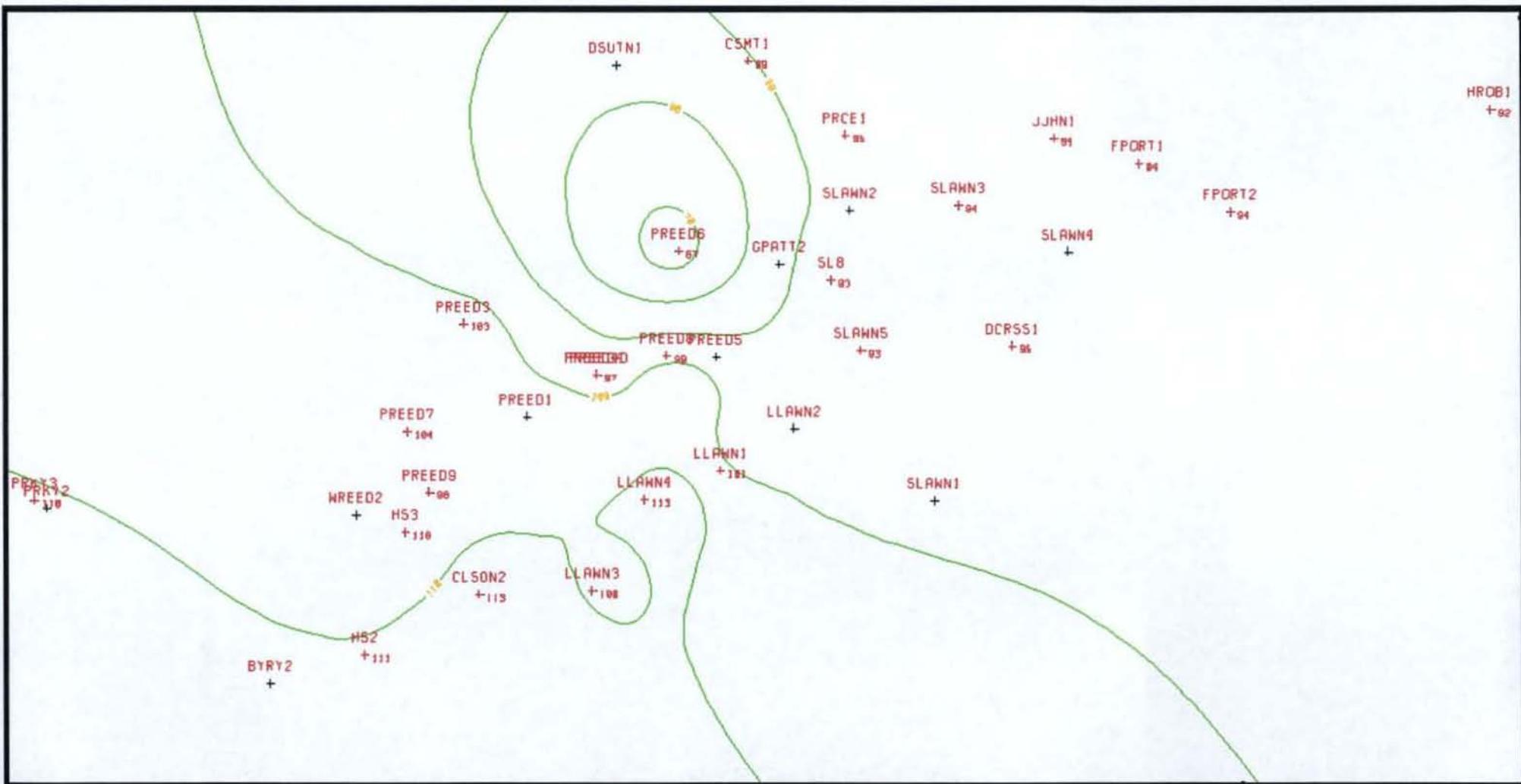


Figure B.7 - Isochore map of the Wells Creek Formation.

Appendix C: Cross Sections of the Swan Creek Oil Field

Cross Section One

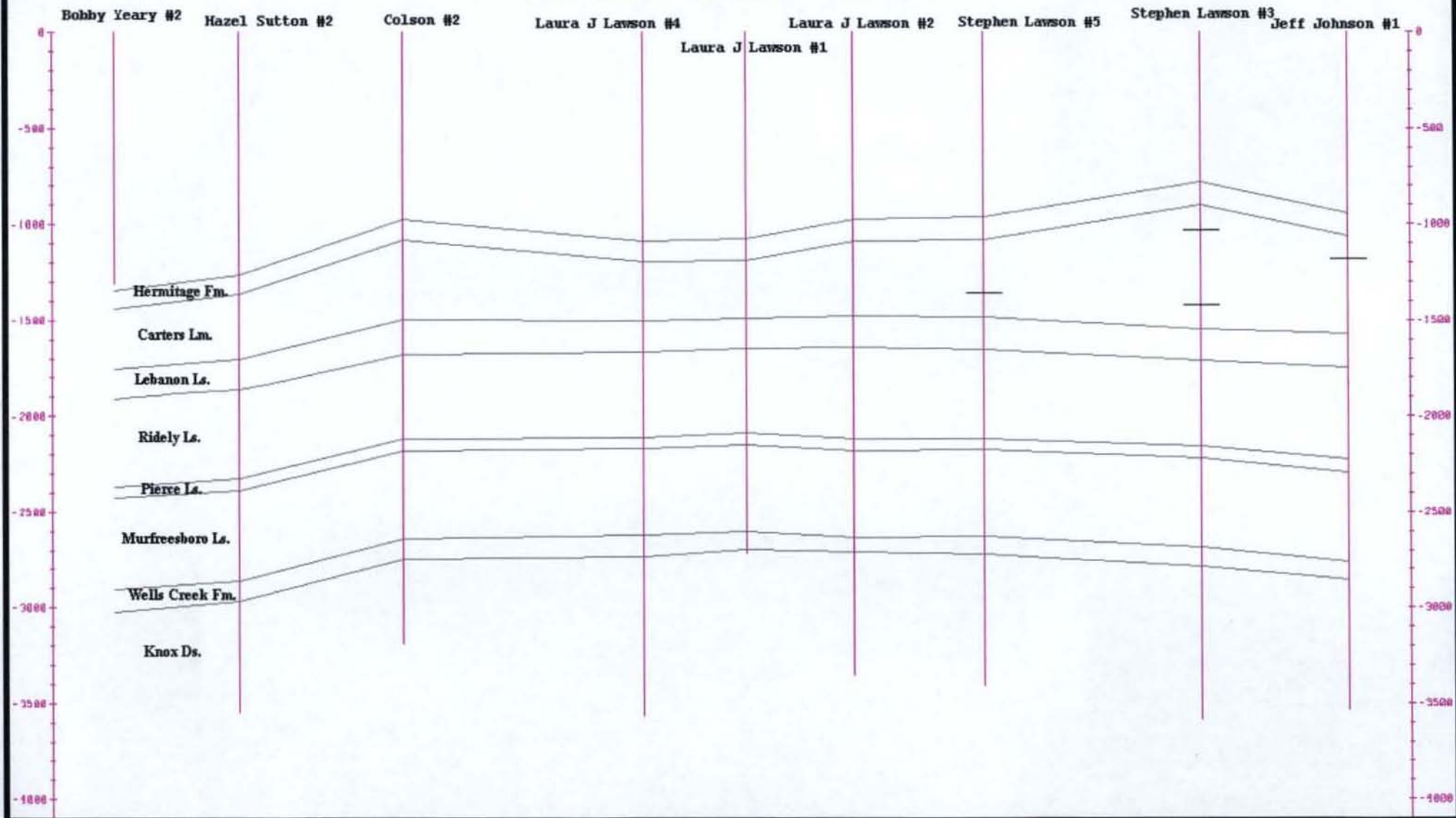


Figure C.1 - Cross-Section One of the Swan Creek Oil and Gas Field

Cross Section Two

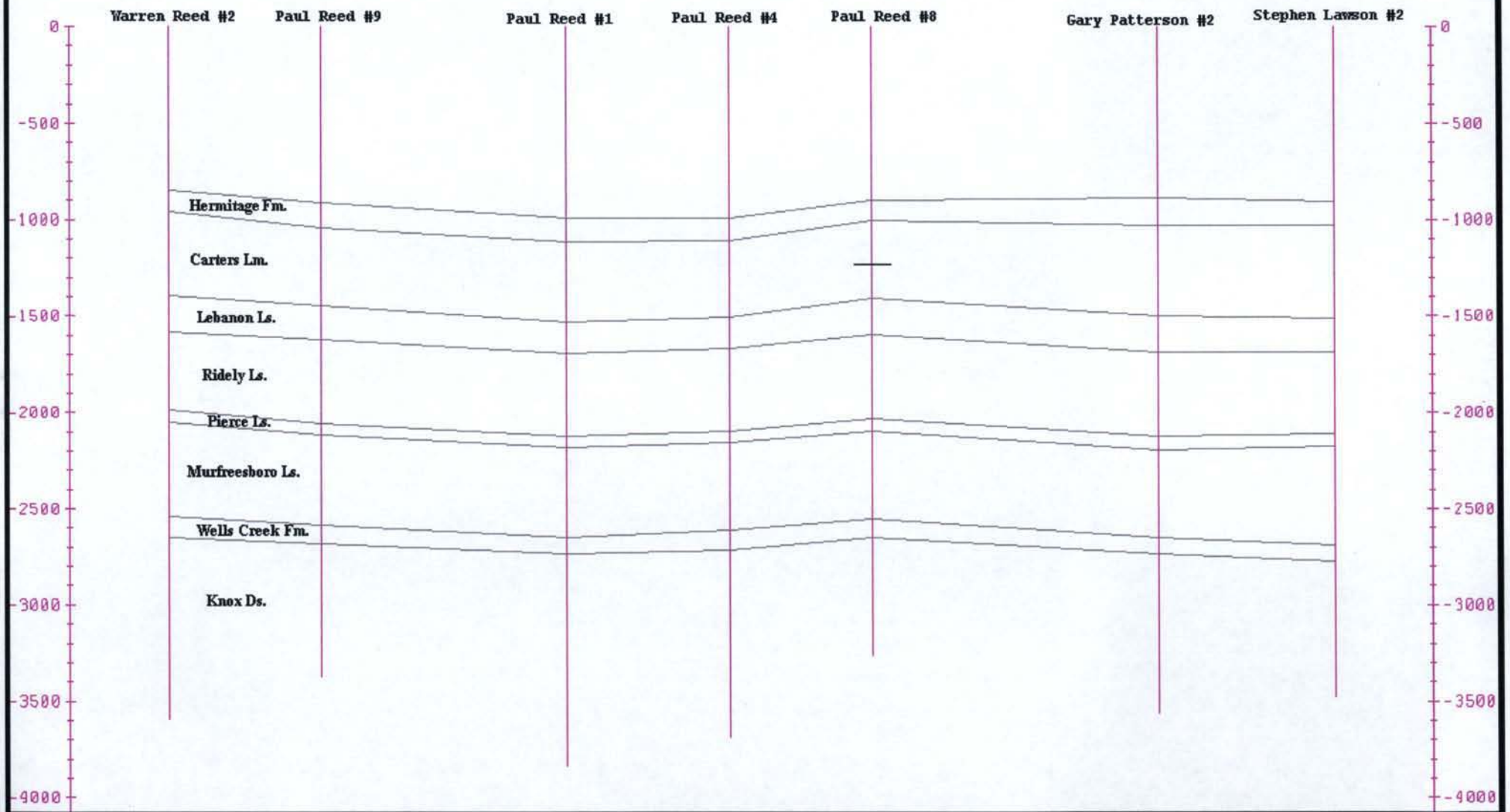


Figure C.2 - Cross Section Two of the Swan Creek Oil and Gas Field

Cross Section Three

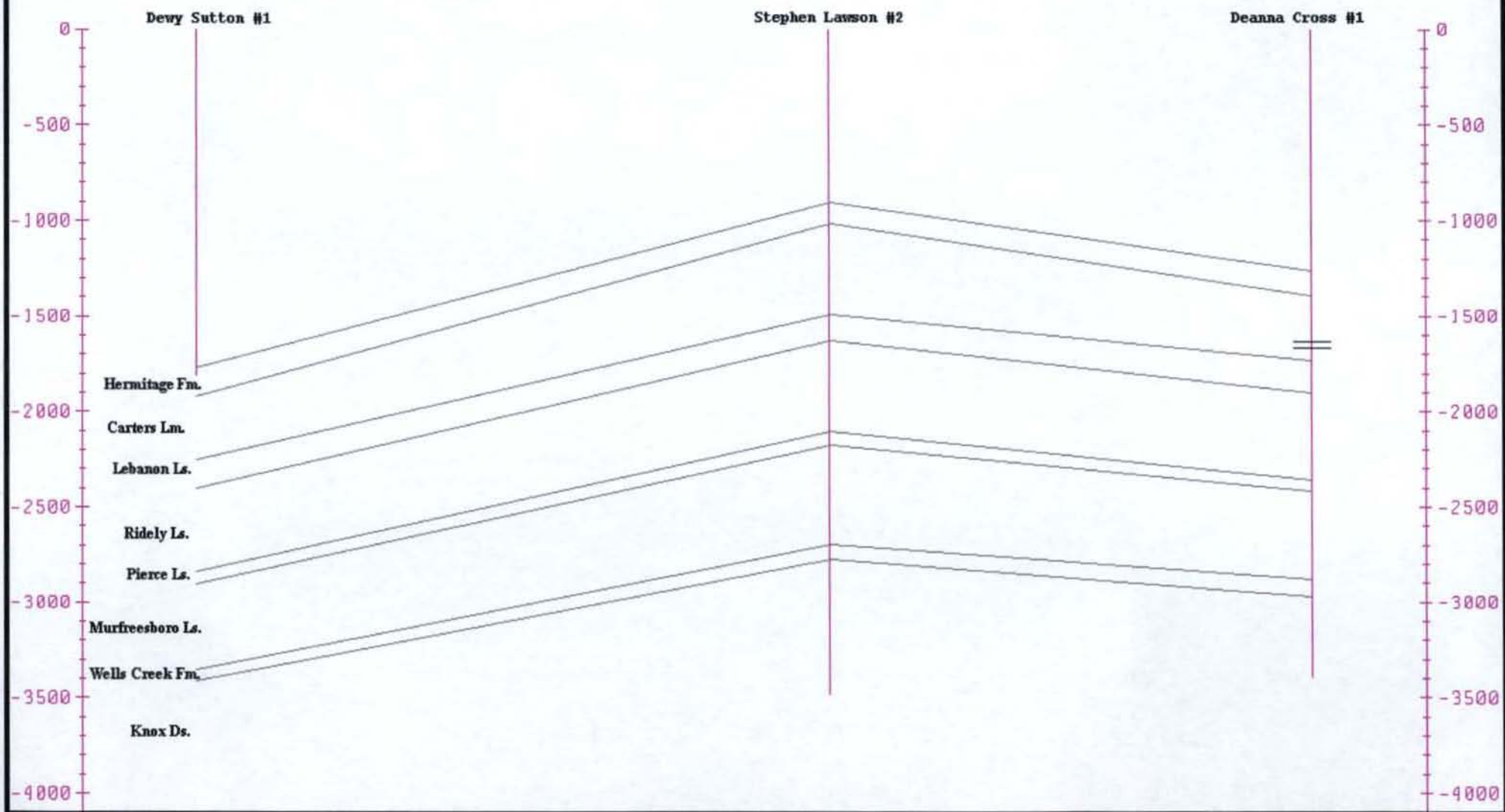


Figure C.3 - Cross Section Three of the Swan Creek Oil and Gas Field

Cross Section Four

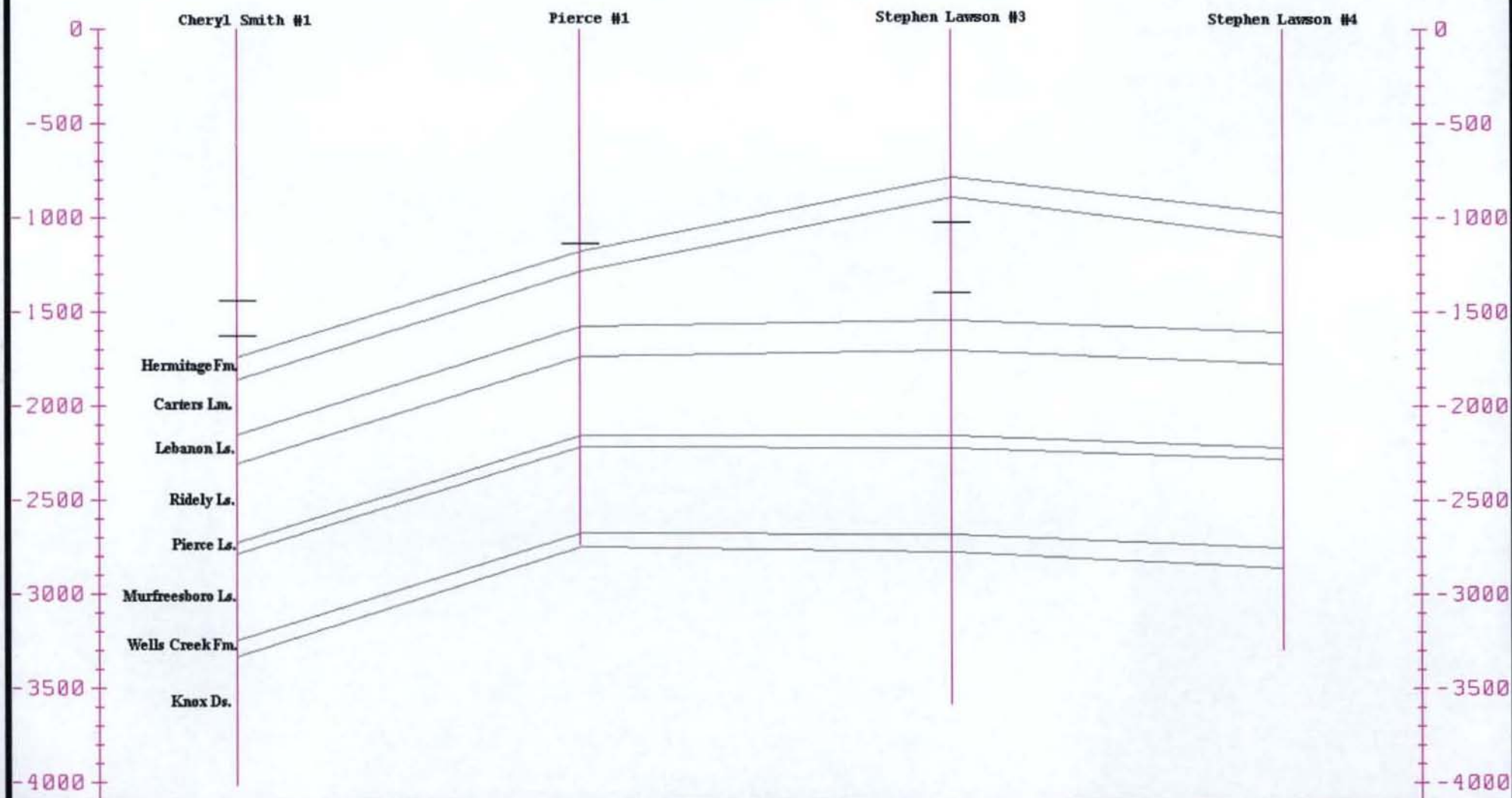


Figure C.4 - Cross Section Four of the Swan Creek Oil and Gas Field

Cross Section Five

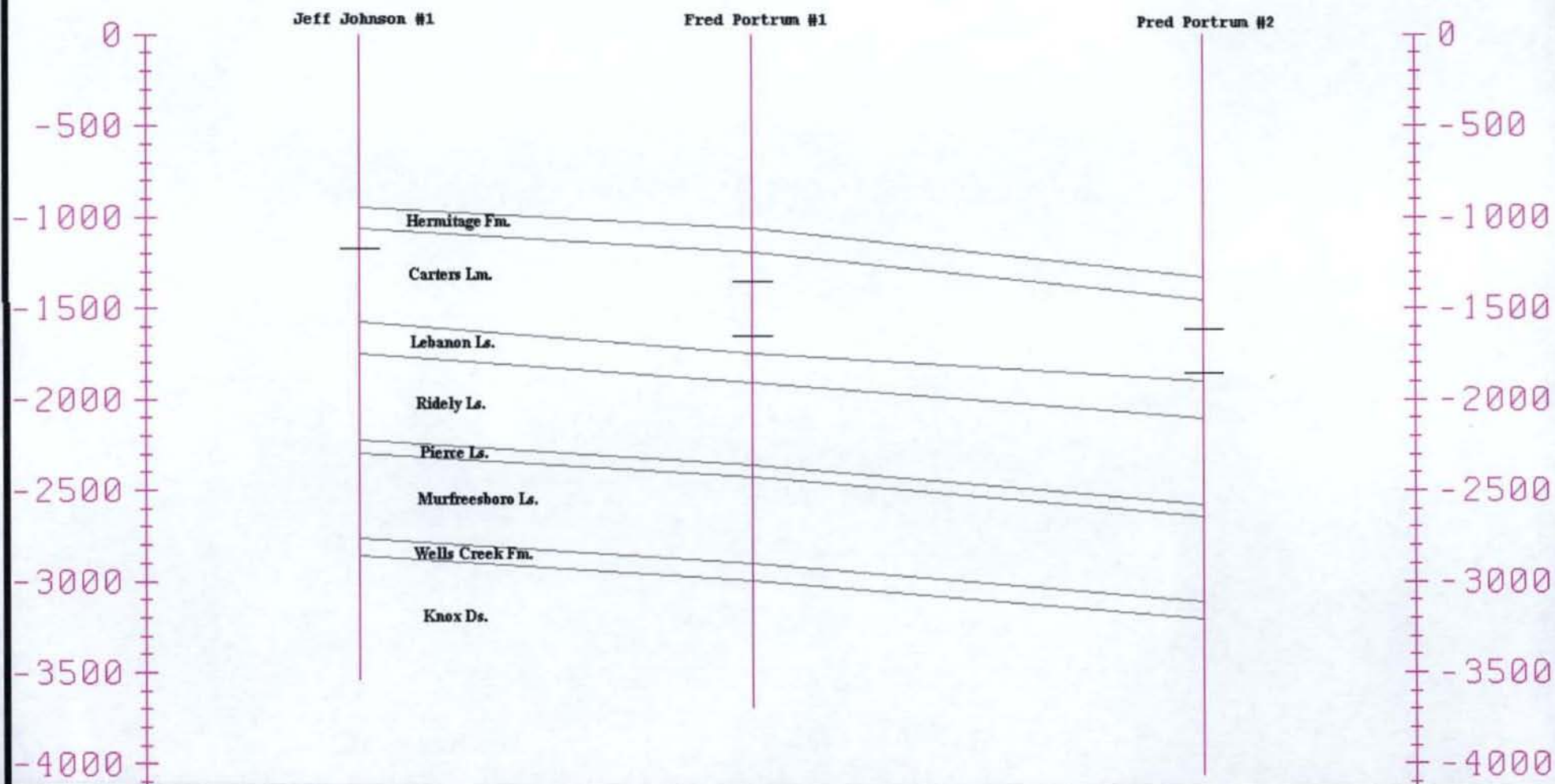


Figure C.5 - Cross Section Five of the Swan Creek Oil and Gas Field

Cross Section Six

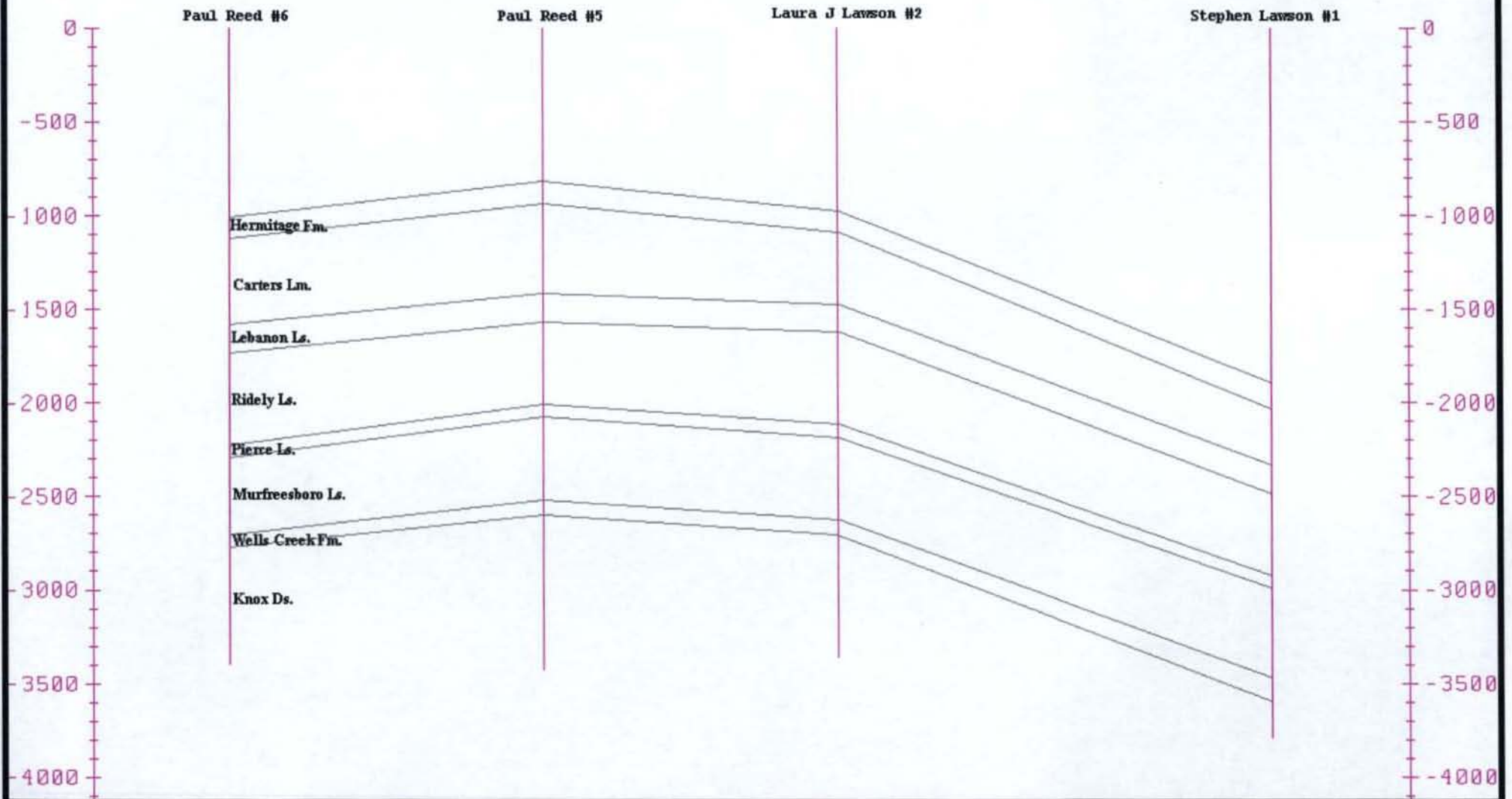


Figure C.6 - Cross Section Six of the Swan Creek Oil and Gas Field

Cross Section Seven

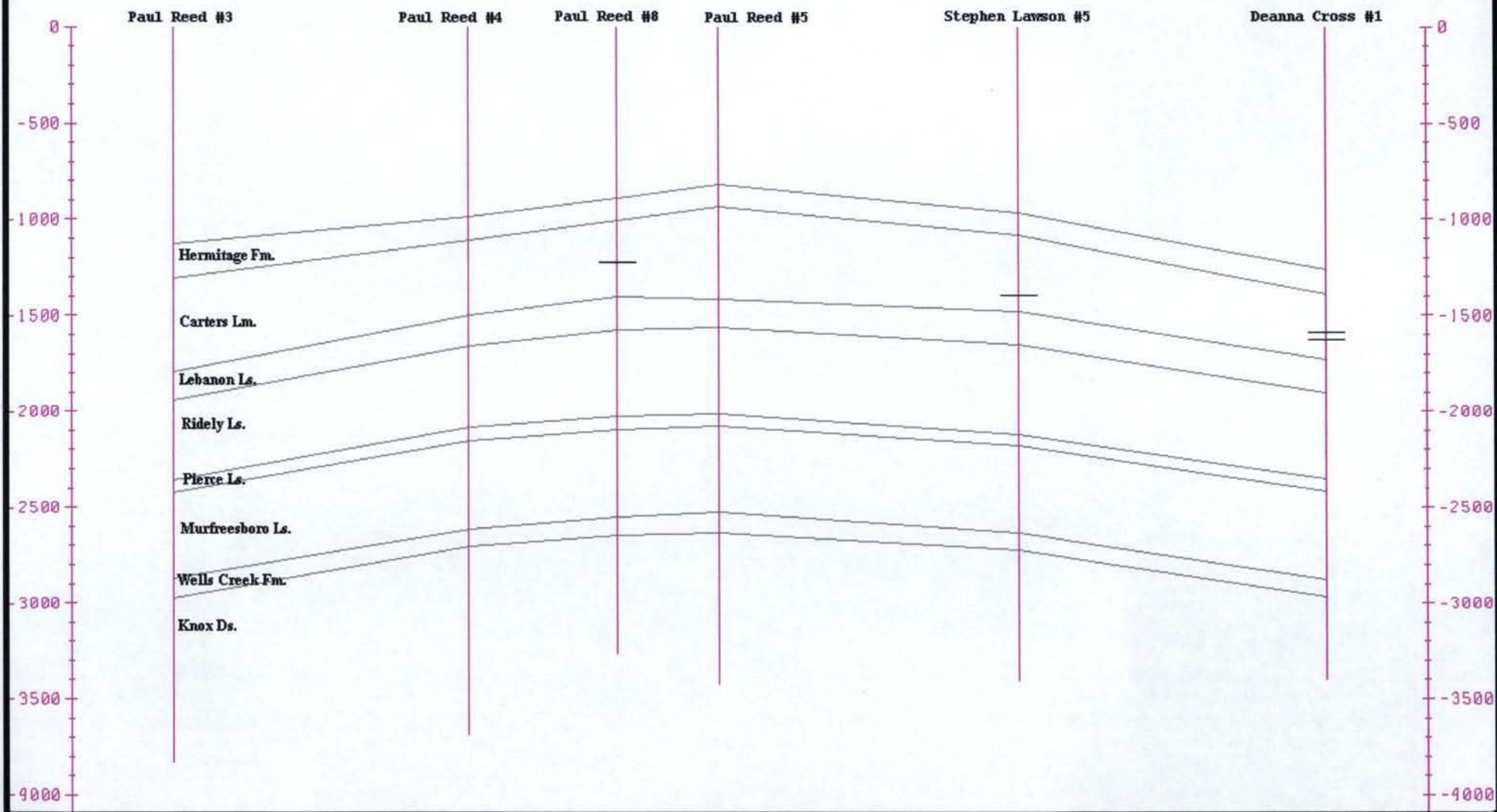


Figure C.7 - Cross Section Seven of the Swan Creek Oil and Gas Field

CrossSection Eight

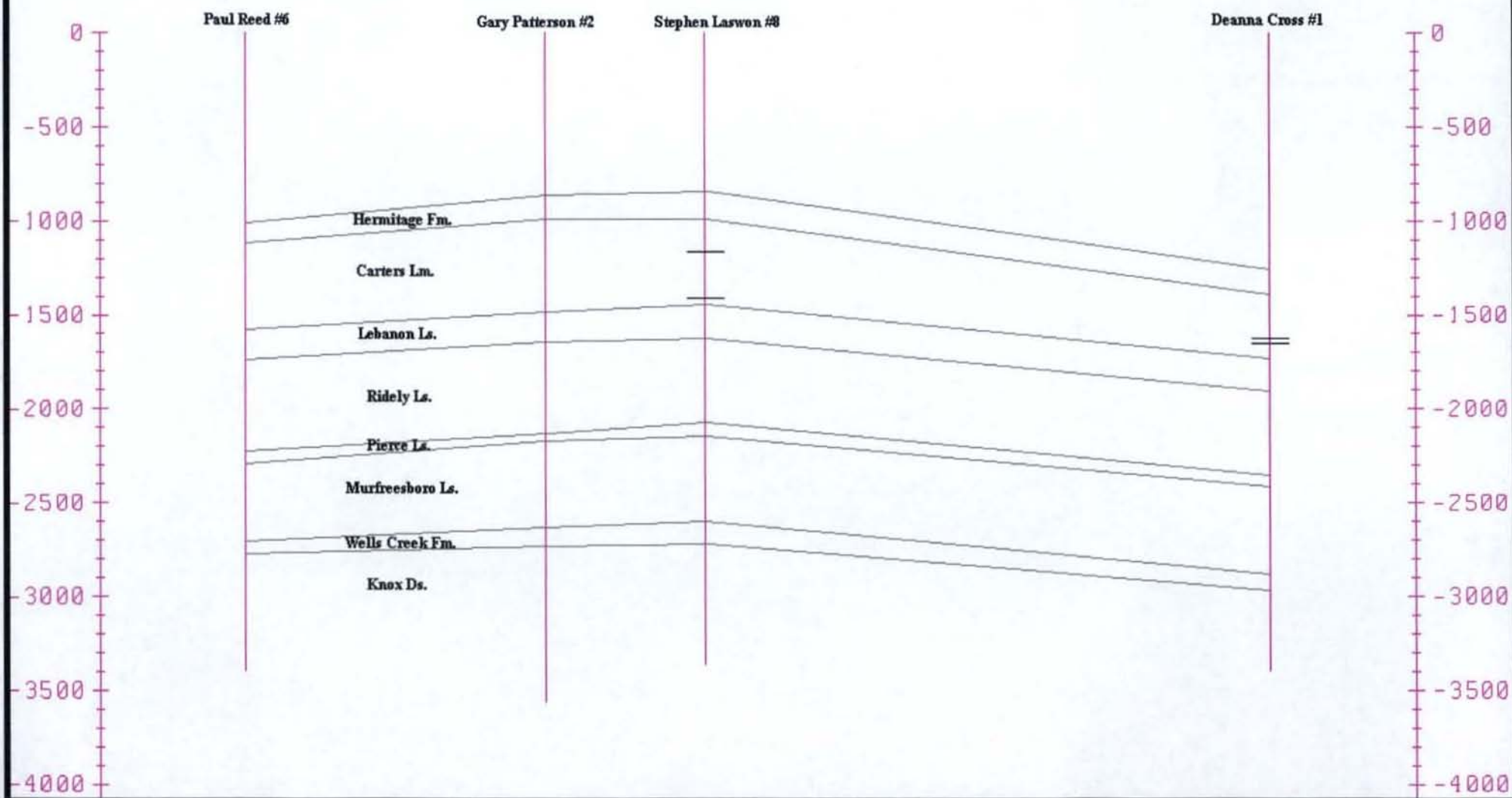


Figure C.8 - Cross Section Eight of the Swan Creek Oil and Gas Field

Cross Section Nine

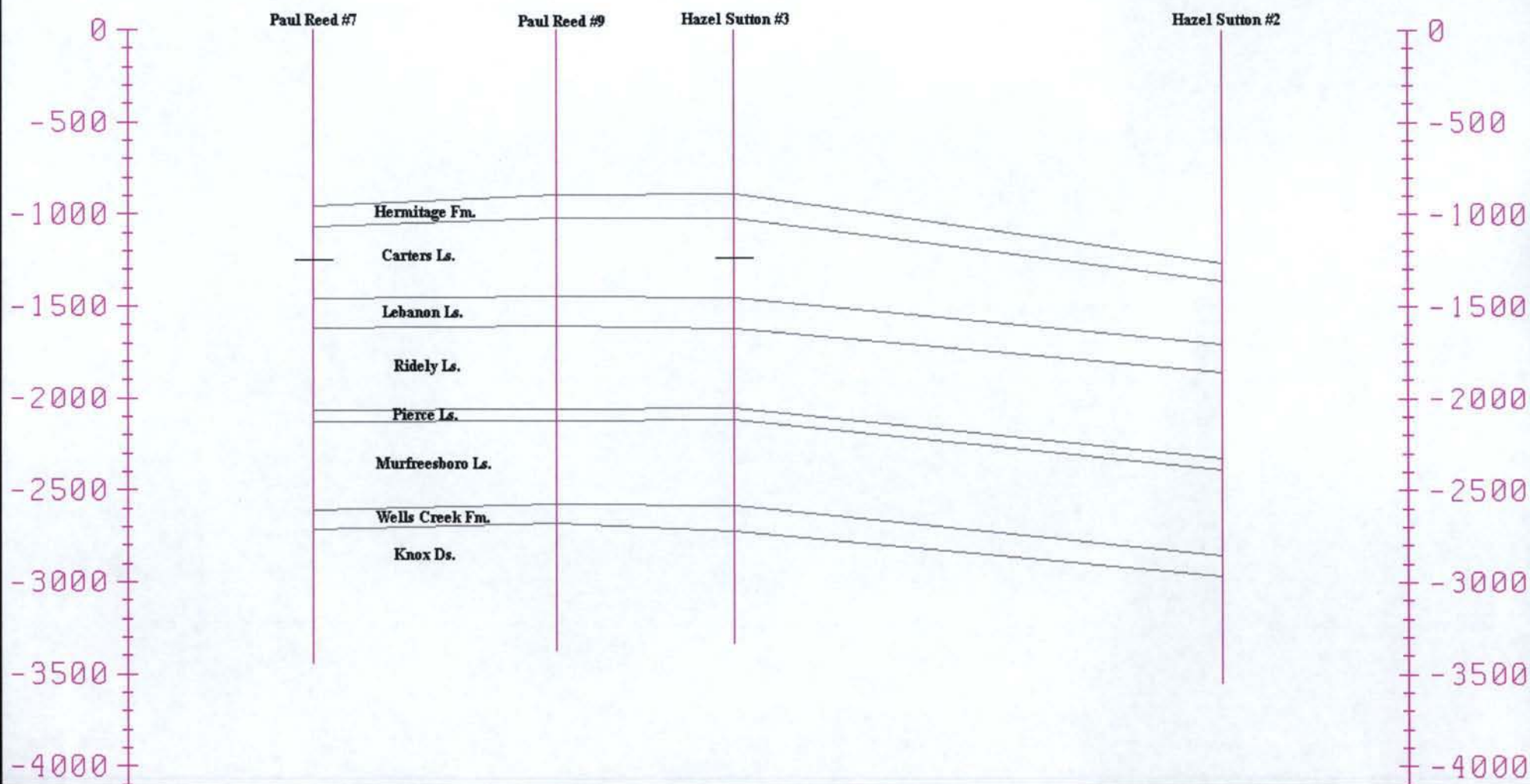


Figure C.9 - Cross Section Nine of the Swan Creek Oil and Gas Field.